ELECTROMAGNETIC FIELDS: BIOLOGICAL EFFECTS and HYGIENIC STANDARDIZATION

Proceedings of the International Meeting
«ELECTROMAGNETIC FIELDS: BIOLOGICAL EFFECTS AND HYGIENIC STANDARDIZATION»
Moscow, 18-22 May 1998

Editors:
M.H. Repacholi
N.B. Rubtsova
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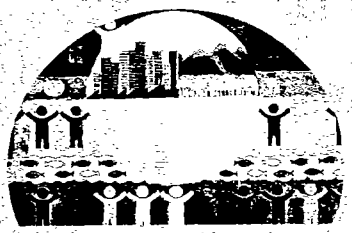

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World Health Orgainzation, Geneva, Switzerland
1999

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Foreword

An International Meeting on "Electromagnetic Fields: Biological Effects and Hygienic Standards", was held in Moscow 18-22 May 1998. The meeting was sponsored jointly by WHO's International EMF Project, the Russian Academy of Medical Sciences (RAMS) Institute of Occupational Medicine and the Centre of Bioelectromagnetic Compatibility within the Institute of Biophysics.

Important objectives for this meeting included bridging gaps in scientific literature on the biological and health effects of exposure to EMF that have been published in Russian and creating an awareness of a significant portion of the science that has accumulated in Eastern European countries. Much of the scientific literature from countries of the former Soviet Union has been published in Russian and so has not been readily available to other scientists in the world.

Russia was the one of the first countries to start fundamental research into biological and health effects of EMF. The Soviet government introduced the first hygienic standards limiting EMF exposure as early as the late 50's. Russian research suggests a relationship between the intensity and duration of EMF exposure and the reaction of human body to it. This was used in developing occupational and other standards based upon a dose-response approach. Such scientific information needs to be better understood by the wider scientific community.

The International EMF Project's evaluation of possible health risks of EMF exposure would be incomplete without taking into account the results of any high-quality research carried out in the former Soviet Union. One of the major objectives of the symposium was to encourage global collaboration among scientists, to develop free flow of scientific information, especially in the area of human health, and to highlight the contribution of CIS countries in this area.

In addition, it is clear that for decades the standards limiting human exposure to EMF have been more restrictive in the former Soviet Union than in other parts of the world. These standards are still in effect in the CIS countries. There has been little understanding outside the CIS about the scientific research that forms the basis for these limits. This symposium is to help the greater scientific community gain a better understanding of this rationale.

The proceedings of the presentations are available in both Russian and English, as provided by the authors. In some cases differences were found between the Russian and English texts. These differences were resolved as best as possible

by the WHO translator. However, WHO takes no responsibility for the accuracy of scientific content of these papers. WHO is merely providing the service of well translated Russian texts into English so that a better understanding of the Russian EMF science can be achieved.

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Proceedings of the International Meeting
"ELECTROMAGNETIC FIELDS: BIOLOGICAL EFFECTS AND HYGIENIC STANDARDIZATION"
Moscow, 18-22 May 1998

Opening of the Meeting

N.F. Izmerov
Director, SRI (Scientific Research Institute) for Occupational Medicine, RAMS
(Russian Academy of Medical Sciences)
and Academician, RAMS

Dear colleagues,

On behalf of the Russian Academy of Medical Sciences let me greet the participants of the international symposium "Electromagnetic fields: Biological effects and hygienic standardization" sponsored by the international programme of the VOZ (World Health Organization, WHO). We thank the WHO, and Dr. Repacholi personally, for the honour that organizing and conducting this meeting bestows on the SRI for Occupational Medicine, RAMS, as a WHO Collaborating Centre. We shall do everything possible to make it successful.

For the first time in the past decade, leading scientists from Russia, the Ukraine, Belorussia, eastern and western European countries, and also the USA have gathered together to discuss current questions about electromagnetic field biological effects and hygienic standardization through the various frequency ranges.

The organizers of the meeting are the Russian Academy of Medical Sciences (RAMS), the RAMS SRI (Scientific Research Institute) for Occupational Medicine, and the Centre for Electromagnetic Safety, Institute of Biophysics, Ministry of Health, Russian Federation.

Over the past 10 - 15 years, in Russia, the Ukraine and Belorussia, there have been carried out numerous studies dedicated to the elucidation of various aspects of EMR (Electromagnetic Radiation) biological effects, the verification of hygienic regulations and the investigation of electromagnetic biological and medical problems that are not commonly studied in the world at large.

In addition, it should be pointed out that Russia was the first country in the world to begin carrying out fundamental research to study the biological effects of EMR. These researches served as a basis for establishing state level hygienic regulation of EMR effects on workers and the general population.

In 1953, at the SRI for Occupational Medicine, there was established a laboratory which was the first in the system of medical institutions affiliated with the MZ (Ministry of Health) of the (former) USSR dedicated to the study of occupational hygiene and research on EMF biological effects. A major role in the organization and establishment of this laboratory was played by Academician A.A. Letavet and Professor Z.V. Gordon. During the early years, the bulk of the research was aimed at the solution of problems associated with occupational hygiene and the biological effects of extremely high frequency EMR (microwaves). Toward the end of the 50s, studies on the hygienic assessment of high and ultra high frequency EMFs were carried out while toward the end of the 60s the combined effects of EMFs with X-rays and heat was studied. During these years, the state of worker health in different industrial sectors was studied, the clinical manifestations of radiofrequency exposures were described, and the first attempts at clinical/hygienic correlations were undertaken. The results of the research permitted the formulation of a hypothesis about the possible nonthermal effects of low level EMR and served as a basis for establishing the first hygienic standard in the EHF (extremely high frequency) and the development of preventive measures.

During the period from 1976 to 1988, under the direction of Professor B.M. Savin, a reconstruction and re-equipment of the laboratory was carried out and innovative research methods were introduced. Wide-scale studies in the low and extremely low frequency ranges, continuous and intermittent exposures as well as total and partial body exposures in the EHF range were performed.

The further development of the research programs permitted the accumulation of new data on the dependence of whole body responses on the intensity and duration of EMF exposure which was used in hygienic standardization of occupational exposure by adopting a "dose" (power) approach. To begin with, this approach was used to control EHF EMR. Subsequently, it was applied to the whole radiofrequency region and appears to this day in existing standards documents in Russia.

The development of hygienic criteria for EMFs in Russia, contrary to the principles adopted in the majority of western European states and the USA, is based on a complex approach to the assessment of hazardous effects of factors which include hygienic, clinical/physiological, experimental, and, in recent times,

epidemiological data. The PDU (maximum allowable level) of EMF is established by determining the threshold of a hazardous effect inflicted by the factor which, as a rule, is found at the boundary that divides the zone of active adaptation and extremal exposure with the further introduction of a hygienic safety coefficient.

Scientific studies of the problems of electromagnetic safety have been carried out in Russia for several decades as complex investigations performed both in the field and under laboratory conditions using unique setups and contemporary methods.

Based on the research that was carried out, standards documents regulating both occupational and non-occupational EMR exposures over the range of frequencies from static electric and magnetic fields and power frequency EMFs to millimeter waves in the radiofrequency range have been established and developed. Corresponding control methods, methods and means of protection were also developed and preventive measures were recommended.

However, nonetheless, a series of important aspects of this problem still remain to be resolved. Among these are: the chronic effects on humans of low level exposure to EMR of various frequency ranges, the role in bioeffects of the magnetic component of EMR, pulsed and intermittent radiation, modulation, and assessment of the combined effects of EMR with other environmental factors. Both the domestic and foreign literature lack the necessary generalizations to deal with these questions.

This is why this meeting has been convened to discuss the whole spectrum of questions related to this problem which is important to all the people of our planet and to elaborate its recommendations and expectations for future priority research.

Once again I thank all the participants for finding the means to come to Moscow and take part in its work. I am confident that it will be rewarding for each of you - and useful.

Thank you.

THE INTERNATIONAL EMF PROJECT AND RUSSIAN SCIENTIFIC LITERATURE

M.H. Repacholi
World Health Organization, Geneva, Switzerland

On behalf of WHO I would like to welcome you to this very important International Meeting on "Electromagnetic Fields: Biological Effects and Hygienic Standards", held here in Moscow. The meeting is sponsored jointly between WHO's International EMF Project and the Russian Academy of Medical Sciences (RAMS) Institute of Occupational Medicine. The meeting has been coordinated with Prof. Nikolay Izmerov, Director of the Russian Academy of Medical Science's Institute of Occupational Health, Professor Nikolay Bochkov, Vice-President, Department of Medical Genetics, Moscow Medical Academy, and Professor Youri Grigoriev, General Director of the Centre of Bioelectromagnetics Compatibility within the Institute of Biophysics. My sincere thanks to these scientists, and especially to Dr Nina Rubtsova, Executive Secretary of the Organizing Committee of the International Meeting. She has had to bear much of the heavy work associated with organizing such a successful meeting.

There are a number of important objectives for the meeting. It is an effort to bridge important gaps in the existing global scientific evidence on the biological and health effects of exposure to EMF and in the awareness of the significant portion of the evidence that has been accumulated here. Much of the scientific literature from countries of the former Soviet Union has been published in Russian and so has not been readily available to other scientists in the world. This Meeting should go a long way to highlighting the results and achievements of Russian scientists.

Russia was the one of the first countries to start fundamental research into biological and health effects of EMF. The Soviet government introduced the first hygienic standards limiting EMF exposure as early as the late 50's. Russian research has indicated a relationship between the intensity and duration of RMF exposure and the reaction of human body to it. This was used in developing occupational and other standards based upon a dose-response approach. Such scientific information needs to be better understood by the wider scientific community.

The International EMF Project's evaluation of possible health risks of EMF exposure would be incomplete without taking account the results of high-quality research carried out in the former Soviet Union. One of the major objectives of the

symposium is to encourage global collaboration among scientists, to develop free flow of scientific information, especially in the area of human health, and to highlight the contribution of CIS countries in the area.

In addition, it is clear that for decades the standards limiting human exposure to EMF have been more restrictive in the former Soviet Union than in the other parts of the world. These standards are still in effect in the CIS countries. There has been little understanding outside the CIS about the scientific research that forms the basis for these limits. The symposium is to help the greater scientific community gain a better understanding of this rationale.

With the rapid expansion of technologies causing increasing exposure to EMF, especially in mobile telecommunications, there are now challenges to the limit values of standards. Mobile telephones, for example, emit radiofrequency fields from their radiating antennas that could easily exceed the limits of current Russian standards. If there are health impacts from exposure to EMF emitting technologies, they need to be addressed quickly to prevent any major public health consequences.

There will be two major outputs of this meeting:

1. A proceedings book of all presentations published in both Russian and English.

2. A summary report of the highlights of the Russian science.

The International EMF Project is a pro-active Project to review the current science, encourage additional needed research and then complete health risk assessment that could lead to internationally accepted standards for exposure to EMF. In an increasingly inter-connected and inter-dependent world, global standards are important. The technical and commercial difficulties arising from trying to comply with many incompatible national standards are obvious. Importantly, there are also social and health implications from widely different EMF standards. The public reasonably asks why there are such different national views on safety from EMF exposure, and so has less confidence that authorities are protecting their health. If the protection offered by one of the more restrictive standards has been shown to be necessary to protect human health, then why should countries having less restrictive standards put their citizens at some risk. On the other hand, if a set of standards are more restrictive than necessary to protect health, why should a nation deprive its citizens of the ability to use the full

capability to technology or force them to pay the extra costs needed to meet stricter standards.

The International EMF Project is intended to provide:

- independent scientific assessment of health effects from exposure to EMF (0-300 GHz);
- identification of gaps in knowledge requiring further research in order to obtain high quality scientific information that leads to improved health risk assessment;
- encouragement of a focused, high quality research agenda;
- formal WHO/IARC health risk assessment after this research is completed;
- encouragement of internationally acceptable standards for EMF device emissions and exposure limits;
- information on risk perception, risk communication, risk management of the EMF issue; and
- advice for national programmes and non-governmental institutions.

The Project has a management advisory arm, the International Advisory Committee (IAC), and a scientific arm, composed of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and WHO collaborating institutions. Activities of both arms are coordinated and facilitated by the WHO Secretariat. The IAC:

1. Provides a forum for a coordinated international response on the health concerns raised by exposure to EMF fields.
2. Reviews scientific information related to public and occupational health, and environmental management of the EMF issue.
3. Recommends research in area required for improved health risk assessments.
4. Provides oversight on the conduct of the Project.

In addition to ICNIRP, other international organizations involved in the International EMF Project are: International Agency for Research on Cancer (IARC), International Labour Office (ILO), International Telecommunication Union (ITU), European Commission (EC), International Electrotechnical Commission (IEC), United Nations Environment Programme (UNEP), North Atlantic Treaty Organization (NATO). Over 40 national authorities, including the Russian Federation, are also supporting or are interested in the outcome of the Project.

Towards the end of its programme the International EMF Project will publish Environmental Health Criteria (EHC) monographs of the scientific literature on RF, ELF and static fields. These publications have been timed to allow the research identified by the scientific review meetings to be completed so that the results can be incorporated into the final EHC publication. EHC publications are the result of in-depth critical reviews conducted through independent, scientific peer-review groups on various topics related to exposure of people, biological systems and the environment. The reviews will build on excellent reviews already completed and concentrate attention on the major research works already published, as well as the more recent literature. Reviews will be conducted of the peer reviewed literature, however reports and other publications of well conducted research not in the peer reviewed literature will also be considered. The results of this meeting will allow incorporation and a better evaluation of more of the science produced in the former Soviet Union and now being conducted in the CIS countries.

Again my sincere thanks to Prof. Nikolay Izmerov, Professor Youri Grigoriev, and to Dr Nina Rubtsova for their sterling effort on our behalf. I look forward to a stimulating and successful meeting, and fruitful use of the work of this meeting over the next few years. Most importantly, I hope we can make good scientific contacts that will lead to collaboration with Russian speaking scientists for the International EMF Project.

HYGIENIC STANDARDIZATION METHODOLOGY FOR ELECTROMAGNETIC FIELDS AND THE EVALUATION OF THEIR HARMFUL EFFECTS ON THE HUMAN ORGANISM

Yu.P. Paltsev and G.A. Suvorov
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The problem of the biological effect and hygienic standardization of electromagnetic fields (EMFs) as a factor in a person's working and general environment has acquired a special urgency in recent years. This is caused by the rapidly expanding spheres of electromagnetic energy application, the considerable increase in the contingent of people who are systematically exposed to its effect, and the steadily rising EMF levels that create an increasingly large potential danger to the health of broad sectors of the general population (Shandala and Paltsev, 1993). These circumstances make it necessary to further deepen our knowledge in the field of EMF biological effect mechanisms thereby to improve the hygienic standards which are the foundation of the whole system of prophylaxis against their unfavourable effect on the human organism.

The development of the hygienic aspects of the electromagnetic safety problem in Russia is closely connected with a prominent laboratory that was set up in 1953 by A.A. Letavet in the Scientific Research Institute for Occupational Hygiene and Occupational Diseases (now called the SRI for Occupational Medicine, RAMS). Through its efforts the first hygienic standards in the world, regulating permissible levels of EMF on a national level were established. In subsequent years, the workers at this laboratory together with scientists at the collectives of the Northwest Scientific Centre for Hygiene and Public Health (St. Petersburg), the Ukrainian Scientific Hygiene Centre (Kiev), the Kharkov SRI for Occupational Hygiene and Occupational Diseases and others developed normative and methodological documents that were specifically tailored to take account of the biological activity in the existing frequency ranges and the exposed population (occupational, non-occupational, general public).

At the outset it should be noted that hygienic standards for EMF in Russia are developed, as they should be, on the basis of thorough hygienic, clinical/physiological, epidemiological and experimental research. Hygienic studies have the goal of determining the intensity and temporal characteristics of an existing agent. Clinical/physiological studies have the goal of revealing

disturbances in the state of health and physiological functions. Epidemiological studies target the establishing of long-term consequences. And experimental studies are aimed at studying the peculiarities and characteristics of EMF biological effects.

However, experimental studies made a fundamental contribution to the establishment of EMF hygienic standards. This is made evident by the non-specific character of the functional and pathological disturbances which occur in humans under the influence of radiowaves. As a result, in the clinical/physiological and epidemioligical studies, it is extremely difficult to establish the contribution made by EMFs to the development of this or that disturbance in the state of health of the cohort being followed against the background of effects on humans from the other numerous detrimental factors in the environment.

The basis for the hygienic regulation of EMFs, as well as for other factors of a chemical and physical nature, is the principle of preventing their harmful influence on the state of health of workers for the whole of their working lives.

The methodology of hygienic standardization adopted in Russia, based on the concept of a harmful influence threshold for occupational and natural environmental factors, was also used in establishing permissible levels of EMFs. At the same time, the evaluation of the effects of radio waves, from the point of view of their biological significance, gives rise to considerable differences of opinion among experts in the field of electromagnetic biology (Savin, 1988; Paltsev and Nikonova, 1996). In view of the difficulties in interpreting the various biological and biophysical mechanisms that define the end result of EMF effects on the human organism, methodological approaches acquire a major importance within the context of this problem.

In the USA and the majority of the western European countries the establishment of hygienic regulations arises from the concept of a purely thermal mechanism for the action of EMFs founded thereby on the thresholds for detrimental effects on so-called "critical organs" which have an enhanced sensitivity to temperature elevations. Consequently the magnitude of the permissible levels of exposure are determined from purely thermodynamic considerations.

In contrast to foreign countries, the hygienic regulation of EMFs in Russia is based not only on thermal effects, but also on numerous reactions of the organism revealed without temperature rises in biological tissue. This approach to

establishing permissible EMF levels is shared by the majority of specialists in Russia and in recent years by many foreign researchers.

Currently there is a great deal of work available illustrating a great variety of reactions of the (human) organism to the influence of EMFs. Biological effects can appear in the most varied of forms, beginning from barely apparent functional shifts at the limit of the capacity for resolution by existing methods of analysis and ending with strongly pronounced disturbances showing the development of pathology. If, among scientists, there were no difference in the interpretation of the reasons for pathological effects (an example of which could be development of radio wave cataracts), then bioeffects in the form of functional changes of one or another system of the organism would not be interpreted so far from identically. Some authors (Dumansky, 1993) consider it possible to regard any reactions of the organism in response to radio wave effects as an indicator of their unfavourable influence. Others differentiate them into two separate groups of which the first reflects the manifestation of sensitivity to radio waves and the other the development of strains in functional systems with their subsequent breakdown. The differences in the interpretation of the organism's reactions to the effects of EMFs are the most important factor since the final values in hygienic standards depend on them.

The accumulated experimental data allow us to explain many bioeffects as displaying sensitivity to the influence of EMFs. A characteristic feature of the reactions arising in this context is their quick restoration after the action of the irritant is stopped. This range of intensities can be attributed to zone I biological effects. Those EMF intensities that cause development of adaptive and cumulative processes are attributed to zone II. The latter indicate a pronounced stage of disturbance in the functioning of the physiological systems of the organism. Zone III is characterised by EMF intensities that are able to cause stable pathological changes.

In our opinion, the threshold for harmful effects of EMFs should be at the boundary separating the zones of active adaptation and pathological disturbances. However in practice, in the process of carrying out experimental research, the establishment of the threshold for a harmful effect encounters a series of challenges that are difficult to resolve. They depend on the adequacy and sensitivity of the methods used, on the species and body dimensions of the laboratory animals, on the quality of the metrological support, on the qualifications of the researcher and many other things. Therefore, in practice it is not always possible to reproduce and compare the results of experiments carried out by different researchers.

The question of extrapolating data obtained from experiments with animals to humans is very important. Differences in the response of animals and humans to the effects of EMFs depend on a number of factors - sensitivity to shape, differences in energy absorption and distribution, peculiarities in the organization and functioning of organs and systems. It must be admitted that there is a lack of knowledge about the comparative sensitivity of animals and people to the effects of EMFs. However, in a number of studies carried out in Russia these problems have been solved.

In particular, if we start from concepts of the energetics of EMF effects on organisms, considering that, in the last analysis, a biological effect is determined by the quantity of energy absorbed by the organism and by the peculiarities in its spatial distribution in different morphofunctional structures, then it is obvious that the quantifying of ranges must largely be defined by the correlation between the size of a biological object and the length of the irradiating wave.

The results of the research work provide a basis for concluding that as far as peculiarities in EMF energy absorption are concerned, the whole spectrum of electromagnetic radiation would best be divided into three sections, for each of which the methodology and principles of standardization must differ considerably . The first section should comprise EMFs with wavelengths considerably greater than the dimensions of bioobjects. The second section should comprise those with wavelengths that are considerably smaller, and the third, those with wavelengths comparable to the dimensions of a person's body or its separate parts. The corresponding frequency ranges are: up to 30 MHz for the first section and greater than 10 GHz for the second section. A rapid decrease of specific absorbed power with decreasing frequency is a characteristic feature of the first section. For the second section, a characteristic feature is the rapid energy attenuation on penetration into the depth of the tissue, that is, practically all the EMF energy is absorbed in the surface layers of biostructures. A characteristic feature of the third section which occupies the intermediate range between 30 MHz and 10 GHz, is the presence of a number of absorption maxima. In this section, interference phenomena become distinctly apparent. They lead to the expressed dependence of both the overall level of absorption and the absorbed energy distribution on specific wavelength values, the dimensions and anatomic structure of organs and the electrical characteristics of tissues.

Unfortunately, up to the present, the peculiarities in the absorption and distribution of EMF energy discussed above have not obtained the necessary reflection/incorporation in the practice of hygienic standardization and, in particular, in the transfer of experimental results from animals to humans. To a

significant extent this is associated both with insufficiencies in the elucidation of the question and with the serious methodological difficulties in evaluation of the absorption and distribution of EMF energy in biological objects.

For the correct estimation of EMF hazards and the valid extrapolation of experimental results to humans, it is necessary to have regard for the quantitative interconnection between observed biological effects and the quantitative characteristics of the irradiating fields. It is also necessary to know, under different conditions, how the external EMF is connected with the actual internal field, established in the body of the experimental animals or humans, because that is precisely the field that finally defines the biological effect.

At the present time, it is clearly useful for the resolution of the questions about extrapolation to be guided by calculations of the average values of the internal fields and their distributions within phantoms of biological objects. Ignoring the coarse approximation of this approach, which does not take into account the internal structure of the body, the variations in the electrical properties of the tissues, etc., it is undoubtedly a better approximation of reality than the direct carrying over of the threshold levels of irradiation established for animals, to humans. The accuracy of this method of extrapolation is not better than 50-100% compared to the direct transfer where the error can be as much as 1 to 2 orders of magnitude.

The problem of the interaction of EMF energy with biostructures is of major importance in establishing the modern scientific concepts of the biological effect mechanisms for this factor - as a theoretical basis for its hygienic standardization.

One of the fundamental manifestations of the interaction of EMFs with substances in general and with biological structures in particular, is through their heating. However, it has been proved that biological effects of the influence of EMFs can be displayed not only by the action of comparatively high levels of irradiation, that cause an integral heating of the substratum, but also by so called "non-thermal" levels, where no general temperature rise is observed (Gordon, 1996; Presman, 1964). Apparently, for any given intensity of influence , the absorption of EMF energy in tissues leads to the generation of heat, but the distribution of heat can have an irregular character and lead to appearance of internal "hot spots" when EMR intensities are an order of magnitude lower than the overall heating threshold (Shtemler and Kolesnikov, 1978).

Therefore, except where the fundamental possibility of hazardous heating in finely divided biological systems is not relevant, the question of its quantitative evaluation remains open and it does not have any significance.

Together with the problems of extrapolating experimental data through the transition from the thresholds of harmful action to permissible levels, the establishment of a hygienic safety factor - for increasing the reliability of hygienic standards - is also important (Nikonova and Savin, 1979).

An important step in the practice of perfecting hygienic standards in Russia was the introduction of an approach to measurements which allowed the values of permissible EMF levels to be specified depending on the duration of their influence during the course of a working day and thereby to secure a more adequate estimate of personal exposure on the basis of such new indicators as "energy exposure" and "maximum permissible level."

In the opinion of most Russian scientists, the central nervous and the cardio-vascular systems possess the highest sensitivity with regard to EMFs. For the study of the functional condition of the central nervous system (CNS), the most widely applied method is that of conditioned reflexes and behavioural responses. The first of these allows the integral activity of the CNS to be evaluated and its high sensitivity permits the expression of the influence on shifts in the state of nervous processes and the possibility of their quantitative evaluation. The use of behavioural tests makes it possible to realise an adequate evaluation of the integral activity (of the CNS) by means of studying the motive and searching activities of animals.

It is much more difficult to determine the primary symptoms of disturbances in the circulatory system, because, up to the present time, a clearly defined experimental model of cardio-vascular diseases, suitable for humans under the influence of EMFs, has not existed. However, in the opinion of a number of researchers, the most substantial factors in this case are persistent disturbances in the electrocardiogram (EKG), indicating the presence of myocardial hypoxia combined with general hemodynamic disturbances.

An important indicator of the organism's condition is the functional level of its defence mechanisms, its immunoreactivity in particular. Objective indicators of the unfavourable influence of EMFs on the organism's immunobiological defence mechanisms is the persistent decrease in the phagocytic activity of neutrophils, the inhibition of lymphocyte blast transformation, the depression of the organism's

ability to form antibodies, degradation of the bactericidal characteristics of blood, and others.

In the opinion of many authors, the indicators of hemopoietic condition (general clinical blood analysis, examination of the osmoresistance of erythrocytes, and blood coagulation dynamics) can be informative in the study of EMF effects.

In recent years, biochemical methods which are directed at studying hormones (adrenaline, noradrenaline, thyroxin, triiodothyroxin, for example), primarily responsible for the mobilization of energy reserves and the organism's adaptation to extreme influences, have been quite widely adopted.

Among the functions which have an especially important biological significance is the ability to reproduce descendants. Therefore, such indicators of this function as spermatogeny, fertility, foetal development, birth rate and characteristics of offspring are studied rather often with the aim of revealing unfavourable consequences of the influence of EMFs (Lokhmatova and Kleshenok, 1988).

The possibility of mutagenic effects arising from the influence of EMFs at "non-thermal" intensity levels has been established through a series of studies (Koveshnikova and Antipenko, 1991). They have been revealed by the application of special cytogenetic methods using blood cells, bone marrow, corneal epithelium and others.

Thus, the establishment of threshold levels for harmful EMF effects must be based on the evaluation of a complex of indicators, characterising the availability, nature and extent of evidence of functional disturbances in a number of an organism's systems. However, it should be admitted that the solution of this problem on the basis of the analytical principle of comparing indicators acquired before and after the period of irradiation, cannot be considered optimum. The shortcoming of this approach arises from the fact that internal biophysical processes, that occur in the irradiated organism, are obscured.

A more thorough evaluation of the organism's functional systems which are being examined is attained by applying functional loads sufficient to bring the system under examination to its highest level of functioning. Physical work, high or low air temperatures, infrared radiation and others are factors which can be used as such additional loads for establishing harmful EMF effect thresholds. In so doing, the EMF effect on the specific system of the organism under the influence of the additional loads, added to the background stress will be accompanied by

differential shifts in physiological indicators, which permits a more accurate evaluation of the extent of the factor's adverse effect.

The research methods for EMF effects on organisms discussed above indicate the necessity both of standardizing the conditions of carrying out experimental research and of elaborating of unique criteria for the evaluation of biological effects, without which it is impossible to establish a sufficiently exact threshold level of adverse effect for the factor.

Such, by way of a short summary, is the methodology of evaluating the adverse effects of EMFs on organisms and establishing hygienic standards which has been adopted in Russia and which is being supported by most of the experts in the field of electromagnetic biology.

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CRITERIA FOR THE DEVELOPMENT OF INTERNATIONAL STANDARDS

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INTRODUCTION

Increasing technical applications of non-ionizing radiation (NIR) in every day life and potential effects of exposure to static and time varying electric, magnetic, and electromagnetic fields are causing significant public and occupational health concerns and need scientific clarification. Biological effects and possible health consequences of exposure to electromagnetic fields (EMF) need to be assessed according to an appropriate set of guidelines. It should, however, be realized that a complete system of setting and practical implementation of international standards needs a cooperation of different national and international organizations. Four requirements can be formulated to define the role of different organizations:

a) Assessment of possible adverse health effects on the basis of established scientific and medical knowledge; recommendation of health based guidance on limiting exposure.

- The focus of this requirement is life science, based solely on science, free from vested interest.

- The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is the independent international body which works with WHO to assess health effects and uses this as a basic to draft health based exposure guidance. ICNIRP is qualified to carry out this task.

b) The provision of technical advice concerning practical implementations needs a translation of the biologically based restrictions into a practical system of implementation.

- This requirement includes guidance on the principles and the practice of measurement, design, of equipment, setting emission limits etc.

- This concerns physics, engineering and technology.

- International, regional and national technical standard bodies (i.e., IEC, ISO, CIE, CENELEC) should carry out this task.

c) The assessment of compliance and enforcement in the workplace and in the public environment requires input from health based guidance and technical advice concerning practical implementation.

   - These tasks are carried out by occupational and public safety and radiation protection professionals.

d) The enforcement of compliance and assessment of the social and economic impact.

   - This is the responsibility of national governments and their agencies.

CRITERIA FOR EVALUATING SCIENTIFIC LITERATURE AND DEVELOPING EXPOSURE STANDARDS

The development of international EMF standards requires a critical in-depth evaluation of the established scientific literature since to base standards on preliminary data or unproven hypotheses could mean that the limit values may change significancy with further research. Using established scientific literature allows exposure restrictions to be determined with a higher degree of confidence about their protective value.

Literature for review should have been published in scientific peer re view journals. While peer review adds confidence in the study results, for health risk assessment, additional review is necessary to evaluate study design, conduct and analysis of each report, and to compare them with the results of other studies, Detailed guidelines on the conduct of high quality laboratory research can be found in NTP (1992), FDA (1993), Repacholi and Stolwijk (1991) and Repacholi (1998). Essential points are summarized in table 1.

Criteria that have been widely accepted when evaluating epidemiological studies have been recently summarized by Repacholi and Cardis (1997). Under these criteria, strength and consistency of the association between EMF exposure and biological effects, evidence of a dose-response relationship, evidence provided by laboratory studies, and plausibility that biological systems exposed to EMF fields manifest biological effects, are all examined (see table 2).

Table 1
Essential points for the conduct of high quality laboratory studies

- Experimental techniques, methods, and conditions should be as completely objective as possible and based on biological systems appropriate to the endpoints studied
- All data analyses should be fully and completely objective, with no relevant data deleted from consideration, and with uniform use of analytical methods
- Published descriptions of methods should be given in sufficient detail that a critical reader would be convinced that all reasonable precautions were taken and that other researchers can reproduce them.
- Results should demonstrate an effect of the relevant variable at a high level of statistical significance using appropriate tests.
- Results should be quantifiable and susceptible to confirmation by independent researchers, Preferably, the experiments should be repeated and the data confirmed independently.
- Results should be viewed with respect to previously accepted scientific principles before ascribing them new ones, Research findings pointing to previously unidentified relationships should be carefully evaluated and appropriate additional studies should be conducted before the findings are further considered.

Furthermore, criteria must be developed to identify which EMF-induced biological effects are to be considered a hazard to human health, A destination needs to be made between the concepts of interaction, biological effects and health hazard. In table 3 some definitions are summarized which may be a help for assessing interactions, biological effects and health hazards (Repacholi and Stolwijk, 1991).

For exposure to any physical agent, there exists a range of biological effects that needs to be assessed for determining health effects. From the assessment of health hazards from exposure to NIR, a dose response relationship exists. At very high doses clearly adverse physiological effects occur, and a threshold can generally be defined for producing these effects. A consensus of scientific opinion frequently exists which enables one to delineate the range of exposures where no

adverse effects occur or appears possible. Controversy sometimes occurs however with regard to the grey area in between these two dose ranges.

Table 2
Factors in assessing epidemiological studies

- Is there a clearly associated risk with exposure (risk ratio of 5 or more)? A weak association is more susceptible to bias and confounding. Supporting evidence in laboratory animals would be important to increase confidence.
- How consistent are the studies of association between exposure to EMF fields and the risk of cancer? Do most studies show the same risk for the same disease'?
- Is there a dose - response relationship between measured, calculated, or estimated EMF fields and cancer rates?
- Is there laboratory evidence for an association between exposure to EMP and the risk of cancer? The weight assigned to studies of whole animals is greater than the weight assigned to studies of isolated tissues and cells because of the absence of systemic regulatory controls and mechanisms in cells and tissues.
- Are there plausible biological mechanisms for a link between EMF field exposure and the risk of cancer'? The biological significance of responses observed *in vitro* should not be assumed unless it has been demonstrated that similar responses do occur *in vivo* and are relevant to human health effects.

Once threshold exposures are established, safety factors may be incorporated into the limits depending on the degree of certainty about the threshold dose. Safety factors in health protection standards do not guarantee safety, but represent an attempt to compensate for unknown and uncertainties.

An important part of the rationale for any exposure standard is the definition of the population to be protected. Occupational health standards are aimed at protecting healthy adults exposed as a necessary part of their work, who are aware of the occupational risk and who are likely to be subject to medical surveillance.

General population standards must be based an broader considerations, including health status, special sensitivities, possible effects on the course of various diseases, as well as limitations in adaptation to environmental conditions and responses to any kind of stress in old age. In most cases these considerations will have been insufficiently explored, so standards for the general population must involve adequate safety factors.

Table 3
Interactions and biological e effects versus health hazards from exposure to EMF fields

- Interaction is by inductive and capacitive coupling or forces on charged particles, which may result in a negligible physical perturbation.
- A biological effect is a detectable change in function or Structure above the molecular level, a physiological perturbation that may or may not be measurable. Living systems respond to many stimuli as part of process of living; such responses are examples of biological effects
- Measurable biological effects that remain within the normal range of physiological compensation of the body and do not detract from the physical and mental well being of humans should not be considered as hazardous.
- Interactions which lead to biological effects outside the normal range of compensation of the body may be an actual or potential health hazard.
- Biological effects that compromise an individuals ability to function property or recover from a stimulus should be considered a health hazard,
- Subjective effects, if !substantiated (i.e., studies conducted in scientific manner, results statistical significant, direct causal relationship), can detract from the physical and mental well being of a person, should be considered as a health hazard.

ICNIRP GUIDELINES FOR LIMITING EXPOSURE TO TIME VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)

ICNIRP is the formally recognized non-governmental organization in NIR Protection for the World Health Organization (WHO), the International Labour Organization (ILO) and the European Union (EU), and maintains a close liaison and working relationship with other international bodies engaged in the field of non-ionizing radiation protection. A review of general activities of the ICNIRP has been published recently (Bernhardt and Matthes, 1997).

ICNIRP is the independent scientific body, comprising all essential scientific disciplines, which works with the WHO to assess health effects of exposure to NIR and uses the results of this assessment to draft health-based exposure guidelines. Recently, the ICNIRP adopted guidelines for limiting EMF exposure up to 300 GHz (ICNIRP 1998). Biological effects reported as resulting from exposure to static and ELF electric and magnetic fields and electromagnetic fields have been reviewed by UNEP/WHO/IRPA (I987, 1993). These publications

and a number of others (Allen et.al., 1991; Michaelson and Elson, 1996; Tenforde, 1996) provide the scientific rationale for these guidelines. Static magnetic fields are covered in the ICNIRP Guidelines issued in 1994 (ICNIRP 1994).

Two classes of guidance are presented: basic restrictions and reference levels.

- **Basic restrictions**: Restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects are termed "basic restrictions". Depending upon the frequency of the field, the Physical quantities used to specify these restrictions are current density, specific energy absorption rate (SAR), and power density, Only power density in air, outside the body, can be readily measured in exposed individuals.

  Different scientific bases were used in the development of basic exposure restrictions for various frequency ranges:

  - Between 1 Hz and 10 MHz, basic restrictions are provided on current density to prevent effects on nervous system functions,

  - Between 100 kHz, and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating,, in the100 kHz-10 MHz range, restrictions are provided on both current density and SAR, and

  - Between 10 and 300 GHz, basic restrictions are provided on power density to prevent excessive heating in tissue at or near the body surface.

- **Reference levels**: these levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Some reference levels are derived from relevant basic restrictions using measurement and/or computational techniques, and some address perception and adverse indirect effects of exposure to EMF. The derived quantities are electric field strength, magnetic field strength, magnetic flux density, power density and currents flowing through the limbs. Quantities that address perception and other indirect effects are contact current and, for pulsed fields, specific energy absorption. In any particular exposure situation, measured or calculated values of any of these

quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measured are necessary.

The restrictions are different for occupationally exposed population and general public. The frequency dependence of the reference levels is consistent with data of both biological effects and coupling of the fields.

The safety factors used in the ICNIRP guidelines have a wide range of values from –2 to >10 (depending upon the extent to which thresholds for health effects are known for direct and indirect field effects at various frequencies). Public guidelines include additional safety factors of 2 to 5 relative to occupational guidelines (depending upon the frequency and the relevant dosimetric parameters). As a consequence of having insufficient information on the biological and human health effects of EMF exposure, a rigorous basis does not exist for establishing safety factors. In the new ICNIRP guidelines, the safety factors vary considerably for fields in different frequency ranges and for different biological end points such as effects of direct versus indirect field interactions. In general, threshold field levels for indirect effects (e.g., responses to contact currents) are better defined than for direct effects, and hence less conservative safety factors are required.

The guidelines do not address product performance standards, or guidance precluding interference with medical devices, nor does the document deal with the measurement techniques for determining the reference values, or protective measures. Basic restriction, reference levels for occupational exposure are for general public exposure and reference levels for time varying contact currents from conductive objects are shown in the tables 4 to 8 in the appendix (from ICNIRP, 1998). For a rationale and future details see ICNIRP 1998.

APPENDIX

ICNIRP GUIDELINES 1998: BASIC RESTRICTIONS, REFERENCE LEVELS FOR OCCUPATIONAL EXPOSURE AND FOR GENERAL PUBLIC AND REFERENCE LEVELS FOR TIME VARYING CONTACT CURRENTS

Table 4

Basic restrictions for time varying electric and magnetic fields of frequencies up to 10 GHz

Exposure characteristics	Frequency range	Current density (Head and trunk) (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Local-ized SAR (Head and trunk) (W/kg)	Local-ized SAR (limbs) (W/kg)
Occupational exposure	Up to 1 Hz	40	-	-	-
	1-4 Hz	40/f	-	-	-
	4 Hz—1 kHz	10	-	-	-
	1-100 kHz	f/100	-	-	-
	100 kHz-10 MHz	f/100	0,4	10	20
	10 MHz-10 GHz	-	0,4	10	20
General public exposure	up to 1 Hz	8	-	-	-
	1-4 Hz	8/f	-	-	-
	4 Hz—1 kHz	2	-	-	-
	1-100 kHz	f/500	-	-	-
	100 kHz-10 MHz	f/500	0,08	2	4
	10 MHz-10 GHz	-	0,08	2	4

Notes:

1. *f Is* the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a crossection of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (-1,1414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f=1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maxirnum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restrictions
5. All SAR values are to be averaged over any 6-min peroid.
6. Localized SAR averaging mass in any 10 g of contiguous tissue, the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f=1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditiory effects caused by thermoelastic expansion, anadditional basic restriction is commended. This is that the SA should not exceed 10 mJ/kg for workers and 2 mJ/kg for the general pubirc, averaged over 10 g tissue.

Table 5

Basic restrictions for power density for frequencies between 10 and 300 GHz

Exposure characteristics	Power density (W/m^2)
Occupational exposure	50
General public	10

Notes:

1. Power densities are to be averaged over any 20 cm^2 of exposed area and any $68/f^{1,05}$ -min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm^2, Should not exceed 20 times the values above.

Table 6

References levels for occupational exposure to time-varying electric and magnetic field (unperturbed rms values).

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field (μT)	Equivalent plane wave S_{eq} (W/m^2)
Up to 1 Hz	-	$1,63 \times 10^5$	2×10^5	-
1-8 Hz	20 000	$1,63 \times 10^5/f^2$	$2 \times 10^5/f^2$	-
8-25 Hz	20 000	$2 \times 10^4/f$	$2,5 \times 10^4/f$	-
0,025-0,82 kHz	500/f	20/f	25/f	-
0,82-65 kHz	610	24,4	30,7	-
0,065-1 MHz	610	1,6/f	2,0/f	-
1-10 MHz	610/f	1,6/f	2,0/f	-
10-400 MHz	61	0,16	0,2	2
400-2000 MHz	$3f^{1/2}$	$0,008f^{1/2}$	$0,01f^{1/2}$	f/40
2-300 GHz	137	0,36	0,45	10

Notes:

1. f as indicated in the frequency range column,
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded,
3. For frequencies between 100 kHz and 10 GHz, S_{eq},. E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding I00 kHz see Figs. I and 2. Between 100 kHz and 10 MHz. peak values for the field strengths are obtained by interpolation from the 1.5- fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, of that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1,05}$ min period (f in GHz).
7. No E-field value is provided for frequencies < I Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table 7

References levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field (μT)	Equivalent plane wave S_{eq} (W/m^2)
Up tol Hz	-	$3{,}2 \times 10^4$	4×10^4	-
1-8 Hz	10 000	$3{,}2 \times 10^4/f^2$	$4 \times 10^4/f^2$	-
8-25 Hz	10 000	4 000/f	5 000/f	-
0,025-0,8 kHz	250/f	4/f	5/f	-
0,8-3 kHz	250/f	5	6,25	-
3-150 kHz	87	5	6,25	-
0,15-1 MHz	87	0,73/f	0,92/f	-
1-10 MHz	$87/f^{1/2}$	0,73/f	0,92/f	-
10-400 MHz	28	0,073	0,092	2
400-2 000 MHz	$1{,}375f^{1/2}$	$0{,}0037f^{1/2}$	$0{,}0046f^{1/2}$	f/200
2-300 GHz	61	0,16	0,20	10

Notes:

1. *f* as indicated in the frequency range column,
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded,
3. For frequencies between 100 kHz and 10 GHz, S_{eq},. E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding I00 kHz see Figs. I and 2. Between 100 kHz and 10 MHz. peak values for the field strengths are obtained by interpolation from the 1.5- fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, of that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1{,}05}$ min period (*f* in GHz).
7. No E-field value is provided for frequencies < I Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table 8

Reference levels for time varying contact currents from conductive objects

Exposure characteristics	Frequency range	Maximum contact current (mA)
Occupational exposure	Up to 2,5 kHz	1,0
	2,5-100 kHz	0,4f
	100 kHz-110 MHz	40
General public exposure	up to 2,5 kHz	0,5
	2,5-100 kHz	0,2f
	100 kHz-110 MHz	20

Note: *f* is the frequency in kHz

Table 9

Reference levels for current induced in any limb at frequencies between 10 and 110 MHz

Exposure characteristics	Current (mA)
Occupational exposure	100
General public exposure	45

Notes:

1. The public reference level is equal to the occupational reference level divided by $\sqrt{5}$.
2. For compliance with the basic restriction on localized SAR, the square root of the time-averaged value of the square of induced current over any 6-min period forms the basis of the reference levels.

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THE ROLE OF MODULATION IN THE DEVELOPMENT OF EMF SOMATIC EFFECTS

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In recent times there has been accumulated an array of data indicating the role of EMF modulation in development of bioeffects. Nonetheless these results have still not taken their (rightful) place among the essential results to be taken into account in developing standards documents concerning EMF exposure of the public.

A great many investigations using different EMF modulation regimes has been carried out in Russia [1 – 22].

The analysis of the data obtained indicates that the development of a variety of reactions of the organism is dependent on the form of EMF modulation: changes in behaviour and conditioned reflex activity, influence on the bioelectroactivity of the brain, on hormonal status and so on.

We have carried out investigations which have confirmed the dependence of the development of bioeffects on modulation frequency and which have shown the key possibility of "memorizing" the modulated electromagnetic signal in the brain at low PPE (power density) [23-25].

1. The influence of modulated low intensity EMFs on cardiac activity

Two sets of experiments were carried out: 1) whole body exposure of an animal, synchronizing the electromagnetic impulse with the "R" wave of the EKG and 2) pulsed electromagnetic irradiation of an isolated frog heart with different modulation frequencies.

1.1 Whole body irradiation synchronizing the electromagnetic pulse with the EKG's "R" wave – "The experiment with backward connection".

The experiments were carried out according to the following protocol: the "R" wave is picked out and serves as a signal for turning on the microwave generator. The turning on of the generator occurred at different offset times from the "R" wave, i.e. the microwave pulse was given in synchrony with distinct

phases of the cardiac cycle. Twenty rats and 15 rabbits were used in our experiments. Whole body irradiation of the animals was carried out under the following conditions: carrier frequency 9.3 GHz, pulse duration 2.5 ms, PPE 200 $\mu W/cm^2$. The duration of each irradiation was 20 min.

We obtained statistically significant changes in cardiac activity: in 30% of the cases bradycardia developed and there were recorded separate ventricular extrasystoles.

1.2 Investigation of the influence of modulated EMFs on isolated stained frog hearts. Establishing the role of the initial cardiac rhythm state in the development of bioeffects from exposure to modulated EMF.

A heart in Ringer's solution ionically equilibrated for cold-blooded tissues can continue to contract for as long as 2 days in the absence of hormonal influence and central nervous system regulation. That permitted us to investigate it for extended periods of time.

The functional condition was estimated from changes in the frequency of the heart contraction rhythm. The basic morphological criterion for the state of excitable heart tissue was the evaluation of the vital staining process of the interatrial septum structures by the dye azyn-neutral-red (NR). The method of lifetime staining with NR permits vizualization of the viability of heart structures and the state of permeability of its membranes. Another vital stain, methylene blue, was used for estimating the state of cholinergic synapses in the autonomic neurons of the Ludvig node.

Both CW and pulse modulated regimes at low levels of PPE were used for the electromagnetic irradiation. The carrier frequency was 9.3 GHz. The modulation frequency ranged from 1 to 100 Hz. The pulse shapes used were rectangular, with a pulse duration of 2.5 ms. The PPE was 0.016 mW/cm^2. The principle of changing the modulation frequency with time while constantly monitoring the selected frequencies (sweeping) was used.

All of the basic experiments were carried out during the spring and summer months on 356 puberal frogs, male Rana tempocaria.

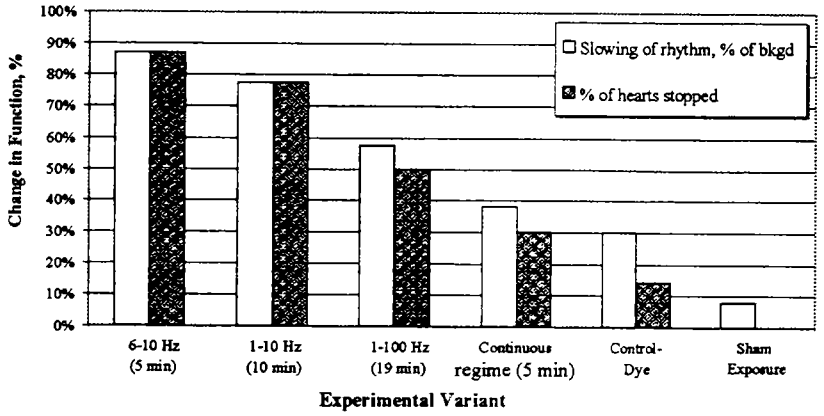
Intact unstained hearts slowed their rate of contraction by 7% on average over an observation period of 24 hours. Heart stopping was observed. Half an hour of presence of the isolated heart preparation in the staining solution in and of itself was the cause of changes in its function. The number of slowings decreased even

more to 30% while 14% of the hearts stopped contracting. Stimulation of arrested hearts with strong light or mechanical agitation of the pacemaker region (sinus venosus) restored their beating. Upon cessation of the process of staining the heart, the rate gradually increased reaching the initial level and only toward the end of the experiment (24 hours later) did the heart contraction rate decrease gradually by an average of 20% (Fig. 1). The reaction of hearts exposed to CW was minimal.

For irradiations using the amplitude modulated regime, a more significant modulated pulse rate decrease was observed for the NK solution and also the number of the hearts arrested increased (Fig. 1). These effects were sometimes reversed. Rinsing the stain from the hearts restored the contractions and the rates rose. However, over the course of the following 2-3 hours, in a large percentage of the cases, there was observed a sharp reduction in the heartbeat and a second stopping of the heart. In these latter cases, stimulating procedures only resulted in short term restoration of heart contractions.

Figure 1. Changes in the number of beating and stopped isolated frog hearts, EM irradiated using the continuous regime and for various pulse modulations from 1 to 100 Hz

(Swept, Meander, Carrier 9.3 GHz, 0.016 mW/cm^2, 160 frogs)



Two to three hours after modulated microwave exposure, disturbances of the granule forming processes in the neurons and muscle fibres of the heart were observed. A large number of the neurons took on an angular form and had a diffuse coloration of the nucleus and cytoplasm. In the muscle fibers the number of granules of dye was reduced, the cytoplasm was lightly stained and many of the muscle cell nuclei were also stained with an intense red coloration. At the same time gelatinization of the synapses in the cells of the Ludvig ganglion and intense

staining of Schwan cells in the zone of the axon conus were taking place. These kinds of changes indicate disturbances in the viability of the exposed structures of the heart leading to the development of a process like paranecrosis.

The second stage of the investigation to establish the role of the initial state of the cardiac rhythm in the development of bioeffects in response to the influence of modulated EMF was also carried out on isolated frog hearts. The microwave exposure was short-term with a PPE of 0.016 mW/cm^2 and modulations with three variants of frequency sets: a) 20, 22, 24, 25, 28 Hz, b) 30, 32, 34, 36, 38 Hz, c) 40, 42, 44, 46, 48 Hz. The chosen frequencies were in accordance with the cardiac rhythm most frequently encountered under our experimental conditions. The exposure duration was 5 min with 1 min at each of the modulation frequencies in the group.

Under these conditions of exposure, changes in the frequency of cardiac contractions were manifested in practically all cases. In order to carry out analysis of the degree of disturbance in the working of the heart in each of the three variants of this series of experiments the heart's functioning was evaluated according to the following four point system. Magnitude of change in heartbeat frequency in % relative to initial magnitude: 10-20% - 1 point; 21-30% - 2 points; more than 31% - 3 points and reversible stopping of the heart - 4 points.

A differential bioeffect dependent on the modulation of the microwave field and associated with the various initial heartbeat frequencies was obtained (Table 1).

Table 1. Changes in frog heart contraction frequency as a function of SHF field modulation and the initial heart contraction frequency

Experimental Variant	Number of Hearts	Modulation Freqeuncy, Hz	Number of Points (average for group) Initial beat frequency of heart			Total
			20 - 30	31 - 40	41 - 50	
I	23	20, 22, 24, 25, 28	50	3	3	56
II	28	30, 32, 34, 36, 38	11	12	9	32
III	22	40, 42, 44, 46, 48	9	1	16	26
IV	26	Continuous Regime	1	-	1	2
Control	30	-	-	-	-	0

Most of the heartbeat frequency changes were observed in variant I of the modulation regimes. Beyond that, in each of the modulation regime variants the largest change was associated in a given sample with the initial heartbeat frequency. In variant I this was 20-30 beats per minute (modulation frequency 20-28 Hz); in variant II it was 30-40 (modulation frequency 30-38 Hz) and in variant III it was 40-50 (modulation frequency 40-48 Hz).

The data obtained in this series of experiments attests to the usefulness of the notions about functional changes in one system or another as a result of the cooperative action of modulation and carrier EMFs and the possibility of the existence of resonant conditions for the absorption of energy under microwave irradiation.

In summing up the results presented above it must be concluded that in experiments using irradiation of isolated frog hearts with microwave fields there was obtained the effect of changing the function of the heart with low PPE intensities (0.016 mW/cm^2). In all the series of experiments involving irradiation of the hearts with modulated fields having changing modulation frequencies from 1 to 100 Hz, there was manifested a significantly greater influence on the function of the heart than those involving irradiation in a field with a continuous regime of generating the EMR. The negative chronotropic effect, which is the established effect of the reversible stopping of the heart during the first three hours after irradiation, was more significant and pronounced. The markedness of the changes was associated with the initial state of the heart. Hearts with initial contraction frequencies of 20-30 beats per minute were found to be the most sensitive to the influence of pulse sequences with frequencies of 20-28 Hz.

The analysis of the data from the present study indicates that among the mechanisms of the observed effects, obviously, there are reversible disturbances in the ionic permeability of excitable membranes of the heart with the development of manifestations of a type of cholinergic effect and the electric disconnection of cardiomyocytes. In other words a decrease in the excitability of nervous and muscular elements and a disturbance in the intercellular interaction processes arises from the irradiation of cardiac structures.

The results of studies published earlier about the influence of modulated EMFs on the heart are in agreement with our conclusions [1, 26-28].

2. The influence of modulated low intensity EMFs on imprinting behaviour.

The experiments were carried out on 129 chicks which we irradiated during the period of embryogenesis with modulated EMFs.

The irradiation conditions for the experimental group, on the 16th day of incubation, were: the carrier frequency was 10 GHz, the pulse modulation was at 10 and 40 Hz, meander, the pulse duration was 2.5 ms, the exposure time was 5 min and the PPE was 40 $\mu W/cm^2$. In parallel, we carried out an experiment under the very same conditions except that the irradiation was CW. The third series was the control with "sham" irradiation. The experiments included several repetitions. The EMF exposures were carried out in an anaechoic chamber. Imprinting was carried out one day after hatching and used a light flash imprint stimulus with a flicker frequency of 10 Hz and 2 Hz. The differential stimulus differed by 8 Hz. The presence of the imprinting was tested 2 days after hatching using the following criteria: latency in responding to the imprint stimulus; the length of time the chick remained near the imprint stimulus and, the number of approaches to and contacts with the imprint stimulus. Statistical analysis was carried out using Student's test, the Fisher test and other methods.

The results of the experiments carried out are presented in Table 2.

Table 2. Formation of imprinting for chicks after irradiation of the embryos with EMFs using continuous and modulated regimes

Series	Series Designation	PPE $\mu W/cm^2$	Exposure Duration, min	Number of Embryos	Number of chicks with imprinting after EMF exposure
1.	Control (Sham Exposure)	-	-	83	81 (97%)
2.	Continuous Irradiation	40	5	27	23 (89%)
3.	Modulated Irradiation	40	5	19	9 (50%)

A comparative analysis of the possible action of EMFs with a PPE of 40 $\mu W/cm^2$ on the formation of imprinting in newly hatched chicks showed that, under our experimental conditions, pulse modulated irradiation proved to be more effective. CW electromagnetic irradiation with a PPE of 40 $\mu W/cm^2$ did not show an action on imprinting. Imprinting occurred in about 89% of the CW irradiated

chicks (it was about 97% in the controls). However, in carrying out analogous experiments with modulated irradiation, imprinting occurred in only about 50% of the chicks.

3. The possibility of fixating a modulated electromagnetic signal in the (embryonic chick) brain.

Imprinting was chosen as the model for investigating the problem. The experiments were carried out on 127 embryonic chicks on the 16^{th} day of incubation. The embryos were irradiated with EMFs in an anaechoic chamber: 10 GHz, PPE 0.04 mW/cm^2 with pulsed modulations of 1, 2, 3, 7, 9 and 10 Hz. The overall duration of each irradiation was 5 min.

Keeping in mind that we were proceeding from the proposition that a modulated electromagnetic signal could be "memorized" by the brain and take on the role of an imprinting signal, the sensitive period for imprinting (24 h after hatching) was skipped. During this period no external stimuli were presented to the chicks. However, 48 h after hatching we presented the chicks with a pseudo imprint stimulus in the form of a blinking light using the same frequency as the embryo was subjected to through the electromagnetic irradiation on the 16^{th} day of incubation or a test stimulus for which the frequency was offset by 8 Hz in all cases.

The control chicks manifested indifference to both sides and only one chick was found more often in the area of the stimulus having a flash frequency of 10 Hz. Among the chicks irradiated with a 10 Hz [modulation] frequency, the response of approaching the stimulus with the 10 Hz frequency was more sharply expressed than for the 2 Hz stimulus. The occupancy duration in the area of the 10 Hz stimulus for the experimental chicks was 159 s while the number of approaches and contacts amounted to 2.5 and 1.8 respectively. For the controls the values were 93 s, 0.5 and 1.3. The difference between the results for the control and experimental groups was statistically significant with $p = 0.05$. The preference indices for the chicks irradiated during embryogenesis according to all the indicators were 0.7, 0.7 and 0.8 which indicates a preference among the irradiated chicks for the stimulus with a frequency of 10 Hz. Among the experimental chicks a clear preference for the stimulus with a frequency of 10 Hz was observed in 56% of the cases. Among the control chicks a preference for the stimulus with a frequency of 10 Hz was observed for 1 (chick). The difference between the control and experimental groups was statistically significant with a probability of 97.5%.

Analgous results were obtained by irradiating 16 day embryos with EMFs having a modulation frequency of 9 Hz. In five control chicks the average values of the preference indices were 0.4 and 0.54 which attested to the absence of preference to any particular test stimulus. And only in one chick was there observed a preference for a light stimulus with a frequency of 9 Hz.

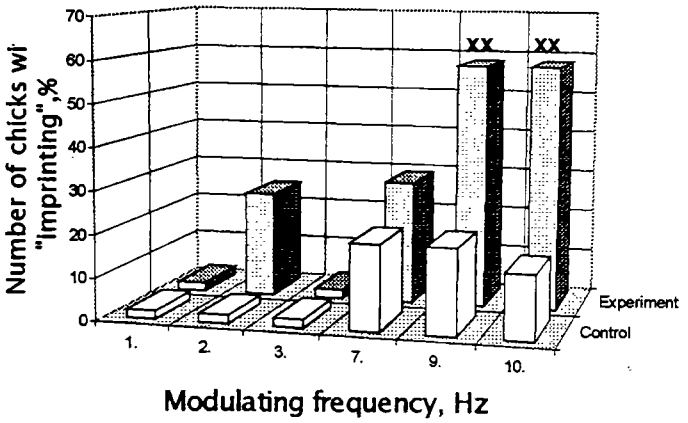
Among nine chicks irradiated during embryogenesis with a frequency of 9 Hz, we observed a different pattern than for the controls. They were found in proximity to the 9 Hz stimulus for a longer duration and were more often in contact with it than the control chicks. From the nine chicks that were irradiated during embryogenesis with a modulation frequency of 9 Hz, five preferred the light stimulus having a frequency of 9 Hz as was indicated by the high stimulus preferences of 0.7 to 1.0 for time in proximity, 0.6 to 1.0 for number of approaches and 1 for contacts.

A different pattern is obtained for the influence of EMFs with modulation frequencies of 7, 3, 2 and 1 Hz on 16 day embryos.

Upon presentation of a light stimulus with blink frequencies of 7 and 15 Hz to chicks which were irradiated during embryogenesis with a modulation frequency of 7 Hz, their response could not be distinguished from the response of control chicks. Among five control chicks a clear preference for a light stimulus with a frequency of 7 Hz was only observed for one. The remaining chicks paid hardly any attention to the light stimulus and the indices of preference among them for the time in proximity, number of approaches and contacts were 0.2. Among chicks irradiated during embryogenesis with a 7 Hz modulation the average values of the indices amounted to 0.2, 0.3 and 0.16 which also indicates the absence of any preference for the stimulus with a frequency of 7 Hz. However among three of the ten irradiated chicks we observed a clearly displayed response of approach to a light stimulus with a frequency of 7 Hz (the preference index for them was greater than 0.5).

For irradiation of embryos with EMFs having modulation frequencies of 1 or 3 Hz, all the chicks (both the controls and those irradiated during embryogenesis) showed no preference for these frequencies (Figure 2). For a modulation frequency of 2 Hz the irradiated chicks showed a preference for a 2 Hz stimulus in only 20% of the cases while among the control chicks any preference was totally absent.

Fig. 2. Number of embryos prefering EM modulated signal



Thus the results obtained indicate that the brains of embryos at the 16th day of incubation can fix an electromagnetic stimulus with a modulation of 9 or 10 Hz in the meander regime and retain this information during the subsequent period.

The results obtained suggest the possibility of an influence of EMF modulation on the development of biological effects at the level of the most complicated systemic interactions of organisms. This permits modulated EMFs to be separated into a special group of radiations whose biological effect depends not only on the magnitude of the absorbed energy, but also on the form of the modulation "addressed" to one or another functional system. This permits us to reach the conclusion that in evaluating the hazards of modulated EMFs it is not only the magnitude of the absorbed energy that it important, but even the very fact of human contact with this form of irradiation is important.

The individual characteristics of human beings and their individual susceptibilities to the specific regime of EMF modulation are both of significant importance.

This phenomenon must be taken into account in the development of hygienic standards documents.

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RADIO FREQUENCY RADIATION RESEARCH PROGRAMS AND SAFETY STANDARDS ACTIVITIES AT THE NORTH ATLANTIC TREATY ORGANIZATION (NATO)

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The North Atlantic Treaty Organization: Structure and Purpose

The North Atlantic Treaty Organization (NATO) was established by the 1949 North Atlantic Treaty, which is commonly referred to as the Treaty of Washington. The North Atlantic Alliance is a defensive alliance based on political and military cooperation among independent member countries, established in accordance with Article 51 of the United Nations Charter. At present, NATO comprises 16 member states including: Belgium, Canada, Denmark, France, Germany (since 1955), Greece (since 1952), Iceland, Italy, Luxembourg, Norway, Portugal, Spain (since 1982), Turkey (since 1982), The Netherlands, The United Kingdom, and the United States.

NATO decisions are taken on the basis of consensus, after discussion and consultation among the member nations. As a multinational, inter-governmental association of free and independent states, NATO has no supranational authority or independent policy-making function. Decisions taken by NATO are therefore decisions taken by all its member countries.

Historical Perspective of NATO Support for Non-Ionizing Radiation Research

NATO historically has encouraged and supported scientific projects concerning Non-Ionizing Radiation (NIR) effects on military personnel, ordinance and fuel. The need for assessment and harmonization of NIR safety guidance continues today, as safety standards are updated throughout the world, and as new NIR systems come on line. Most NIR systems in use and those in development are unique to military applications. The adoption of a scientifically acceptable and defensible standard for human exposure to NIR that is applicable across national boundaries is of significant importance to commanders and operators. Rapidly expanding technologies require that systems hardware and operation be integrated and compatible within NATO.

NATO first recognized, in 1970, the need for coordinated evaluation of NIR impact on military operations. The French proposed to NATO defense Research Group (DRG) AC/243/Panel III (Physics and Electronics) to form Research Study

Group 2 (RSG2) to study the possibility of cooperation in the protection of personnel against NIR. This marked the beginning of twenty-five years of cooperative NATO sponsored research and personnel safety standards development for exposure to NIR.

In June 1973, the RSG2 proposed to the NATO MAS General Medical Working Party (GENMED WP) to coordinate actions on the development of a STANAG concerning personnel safety standards for exposure to NIR. Initially named, 'Biological Effects and Protection of Electromagnetic Radiation,' RSG2 had its first meeting in Aug 1973 in Rijswijk, Netherlands. Member nations including Germany, the Netherlands, Norway, the United States, and The United Kingdom. Canada joined as an active member in Jan 1975.

The Aerospace Medical Panel of the Advisory Group for Aerospace Research and Development (AGARD) cosponsored Lecture Series No. 78 Radiation Hazards[1], in 1975, in the Netherlands, Germany, and Norway, on the subject of Radiation Hazards to provide a review and critical analysis of the available information and concepts. Following that meeting, in the same year, RSG2 proposed a revision to the Standardization Agreement (STANAG) covering personnel safety guidance in RFR hazardous environments. In 1978, several important recommendations where forwarded through the DRG to the MED WP including use of frequency-dependent scaling, use of a continuous curve, and elimination of numerous procedures and restrictions such as the need for EEG and ophthalmic examinations. These changes were documented in STANAG 2345, Control and Evaluation of Personnel Exposure to Radiofrequency Radiation[2], promulgated in 1979.

In 1981, Panel VIII sponsored a workshop at the Royal Air Force Institute of Aviation Medicine (IAM), Royal Aircraft Establishment, Farnborough, U.K. to develop and/or compile sufficient knowledge on the long-term effects of pulsed NIR fields to maintain safe procedures and to minimize unnecessary operational constraints. That workshop brought together eighteen scientists from six NATO countries and resulted in USAF/SAM Aeromedical Review 3-81: A Workshop On The Protection of Personnel Against Radiofrequency Electromagnetic Radiation[3].

Also in 1981, a NATO Advanced Studies Institute (ASI) on Advances in Biological Effects and Dosimetry of Low Energy Electromagnetic Fields was held in Erice, Sicily, Italy. This meeting produced NATO ASI publication: Biological Effects and Dosimetry of Non-ionizing Radiation: Radiofrequency and Microwave Energies[4].

In 1984, Panel VIII sponsored another workshop held in Wachtberg-Werthhoven, Federal Republic of Germany, with over 40 scientists from five NATO countries attending. The proceedings of the second workshop were published as USAFSAM-TP-85-14: Proceedings Of A Workshop On Radiofrequency Radiation Bioeffects[5]. The proceedings begin with an address by Prof. Dr. R. Bernotat (GE) Chairman of Panel VIII, wherein he stated "...this panel has been and is responsible for fostering and coordinating research in the NIR area as well as for transferring knowledge to applications." The need for transfer of technological knowledge on safety guidance and the procedures for implementing that guidance to military organizations is greater now then it was a decade ago.

Also in 1984, a NATO Advanced Research Workshop (ARW) examined the Interaction Between Electromagnetic Fields and Cells[6], in Ettore Majorana Center for Scientific Culture, Erice, Sicily, Italy. The 1984 workshop concluded that "It is important that today's NIR bioeffects research results, emerging from many countries, continue to be disseminated as efficiently as possible for consideration and use by the NATO military organization." The theme of the last AGARD lecture series, which focused on NIR, presented in Italy, Portugal, and France in 1985 was The Impact of Proposed Radiofrequency Standards On Military Operations[7].

The most recent NATO sponsored program on NIR was a NATO ARW on "Developing a New Standardization Agreement (STANAG) for Radiofrequency Radiation" held 16-21 May 1993, at The Divisione Aerea Studi Richerche e Sperimentazioni (DASRS) at the Aeroporto Pratica di Mare Italian Air Force Base, Pomezia (Rome) Italy. An international group of 47 specialists working in the field of biological effects of electromagnetic fields and standards development attended this Workshop to make presentations and participate in discussions on developing standards for human exposures. The state of knowledge in this field of research was examined in great detail. The program was divided into three major sections: Review of Standards, Scientific Basis for New Standards, and Public Health Policy Concerns. The ARW also produced a NATO ASI Proceedings with over 40 papers: Radiofrequency Radiation Standards, Biological Effects, Dosimetry, Epidemiology, and Public Health Policy[8].

International concern for possible biomedical effects from NIR has expanded greatly. The World Health Organization (WHO) has established the EMF Project to evaluate the research and identify knowledge gaps that suggest research needs. The technical representative for NIR personnel safety to the NATO General Medical Working Party and the Radio and Radar Radiation Hazards Working Party has been appointed Liaison to the International Advisory

Committee of the WHO EMF Project. This action will facilitate further coordinated international communication on research and standards setting. Clearly, the ongoing need for communication and activity on issues of NIR health and safety has grown and been recognized by member nations at several levels within NATO and the entire global community.

Current NATO Activities

NATO Scientific Programs

In addition to its well known political and military dimensions, NATO has a "Third Dimension", which seeks to encourage interaction between peoples, to consider some of the challenges facing our modern society, and to foster the development of Science and Technology. The NATO Science Program was founded in 1957 with the establishment of the NATO Science Committee. The objective of the Science Program is the enhancement of science and technology through a variety of support activities aimed at promoting international scientific cooperation. The Scientific Program has been reoriented to point towards addressing scientific and technological problems being encountered by NATO Cooperation Partners. Some of the programs supporting S&T are Collaborative Research Grants, Expert Visits, Linkage Grants, Advanced Study Institutes, and Advanced Research Workshops. New programs are offered frequently such as the recent Science for Peace Program initiative.

Scientific Affairs Division

The NATO Scientific Affairs Division is currently focusing on five Priority Areas, Environmental Security, High Technology, Disarmament Technologies, Computer Networking, and Science and Technology Policy. Support is available for several activities. The purpose of an Advanced Research Workshop is to contribute to the critical assessment of existing knowledge on new important topics, to identify directions for future research, and to promote close working relationships between scientists from different countries and with different professional experience. ARWs are currently supported only in selected Priority Areas and must be held in Cooperation Partner countries.

The High Technology Priority Area is sponsoring an ARW on "Radio Frequency Radiation Dosimetry and Its Relationship to the Biological Effects of Electromagnetic Fields," to be held in Ljubljana, Slovenia 12-16 October 1998. The workshop will review the state-of-the-science dealing with Radio Frequency Radiation (RFR) dosimetry, measurements and the relationships between specific

absorption rate, power density, and the biological effects of electromagnetic energy. The ARW will serve two major purposes: to provide an international forum to determine what theoretical, technological, and scientific events have occurred that should be reflected in a revision of The Radiofrequency Radiation Dosimetry Handbook[9], and to establish working groups to evaluate these advances and determine how to incorporate them into a revision of the Handbook. Information about NATO science program is available at http:/www.nato.int/science.

Research and Technology Organization(R&T O)

In the first major restructuring of NATO's R&T structure in over three decades on January 1998, the Defense Research Group (DRG) and the Advisory Group for Aerospace Research and Development (AGARD) merged, into the R&T O. The R&T Board reports directly to the Conference of National Armaments Directors (CCNAD) and to the Military Committee. The Human Factors and Medicine Panel in the R&T O approved establishment of Task Group 002 (TG-002) "Health Effects of Non-Ionizing Radiation in the Military Setting. TG-002 members include Belgium, France, Germany, The Netherlands, Norway, The United Kingdom, and The United States. Projects to be conducted during the three-year program include the following:

- Research to develop reliable and validated dosimetry and measurement technology. NATO Advanced Research Workshop to be held in Cooperation Partner country Slovenia 12-16 October, 1998.

- Epidemiological studies of military populations exposed to NIR.

- Research on shock and burn factors that lead to shock and burn hazard from NIR.

- Research into possible effects of NIR at the cellular and organ level using military unique emitters.

NATO Standardization Programs

NATO is the world's largest producer of international agreements. The Military Agency for Standardization (MAS) is the principal military agency for standardization within NATO. The MAS was established in London in 1951 and moved to NATO headquarters in 1971 with the goal of meeting the need for "more efficient methods of producing military equipment and of the standardization of

parts and end products of military equipment." Its purpose is to facilitate operational, procedural, and material standardization among member nations to enable NATO forces to operate together in the most effective manner. Standardization and interoperability between NATO forces make a vital contribution to the combined operational effectiveness of the military forces of the Alliance and enable opportunities to be exploited for making better use of economic resources.

The MAS reports directly to the Military Committee, which is the highest military authority in the Alliance under the political authority of the North Atlantic Council and Defense Planning Committee. The MAS includes The Naval Board, Army Board, Air Board, Joint Service Board, and the Terminology Coordinator. Each board has membership from each NATO nation except Iceland, which has no military, and Luxembourg, whose interests are represented by Belgium.

Standardization is voluntary, and is achieved by agreement, not compulsion. Each member has an equal voice. The MAS is an administrative agency with a consultative alliance. Therefore, MAS cannot enforce any agreement; nor can it require national conformity to any policy. MAS authority about standardization only comes from formal agreement of nations, through their representative, within the rule of consensus.

The Working Parties are the most important element of the MAS. These groups are formed by their respective Service Boards and are comprised of groups of experts. It is at the Working Party level that Standardization Agreements (STANAGs) are developed.

Development of NATO Standardization Agreements (STANAGs)

NATO Standardization Agreements for procedures and systems know as STANAGs are developed and promulgated by the NATO Military Agency for Standardization. A STANAG is the official record of agreement among several or all nations to adopt like or similar material or procedures. STANAGs are usually implemented by means of national or NATO command documents.

STANAGs first undergo a process of validation, which ensures that the nations and commands agree that a standardization agreement is required. Next, a standing working party or a special panel carries out the development of a draft agreement. The nation leading the drafting process will normally become the custodian responsible for preparation of the draft and circulating it for comment, collating comments received from nations/comments, and producing the final draft

in consonance with comments received or agreements reached at meetings. Ratification is the stage where an informally agreed draft is formally accepted by nations. Following ratification, the MAS Chairman's signature formally promulgates the STANAG. The STANAGs are reviewed at least once every two years.

Revision of NATO STANAG 2345

The Standardization Agreement (STANAG) 2345, "Control and Evaluation of Personnel Exposure to Radio Frequency Radiation" was signed by representatives of NATO member countries in February 1979. The promulgation of this STANAG represented the culmination of deliberations among scientists and health professionals within the NATO community that began in May 1973.

Edition 1 of STANAG 2345 established criteria for the evaluation and control of personnel exposure to radio-frequency radiation within NATO forces. It defined hazard assessment, allowed for control measures, indicated actions in case of accidental overexposures and established permissible exposure limits. At the time of adoption, it cotained guidance based on the then state-of-knowledge.

In Sep 1991, the Institute of Electrical and Electronic Engineers (IEEE) published C95.1-1991 Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 kHz[10]. The American National Standards Institute (ANSI) recognized and adopted C95.1-1991 in Nov of 1992. The ANSI/IEEE standard was developed after deliberation by 125 internationally recognized scientist experts, many from NATO countries.

The 1993 NATO ARW, Developing a New Standardization Agreement (STANAG) for Radio-Frequency Radiation, initiated the process of revising STANAG 2345. The 1993 ARW produced several recommendations for updating the STANAG 2345. Most important was the agreement to use the newly published ANSI/IEEE C-95.1992 standard as a starting point or strawman for updating STANAG 2345. Thus, the revised STANAG 2345 (Edition 2)[11] is based on the specific absorption rate (SAR), expressed in W/kg, as is the ANSI/IEEE C-95.1992 standard. The STANAG is frequency dependent and covers the range from 3 kHz to 300 GHz taking into account frequency of SAR and gives advice on limitations of plane wave field intensity. It is a single tiered standard, incorporating the controlled values of the ANSI/IEEE C-95.1992, in recognition of the military operational circumstances under which it will be implemented. It allows use of protective clothing, if demonstrated to be effective under operational conditions. The STANAG also provides special considerations for induced and contact current

guidance. Most importantly, the STANAG serves as the Minimum Acceptable Standard for NATO operations and will not supercede National Standards that have Lower (more Restrictive) Permissible Exposure Limits.

International consensus among drafting working group members was reached in 1996. Following review by member nations, unanimous recommendation for ratification of STANAG 2345 by the MED WP occured in Apr 1996. Final promulgation by the MAS was 13 October 1997.

NATO Transition and Expansion

NATO has undergone marked transformation since the end of the Warsaw Pact in 1989 and the breakup of the Soviet Union in 1991. A significant initiative at NATO has been establishment of close security links with the states of Central and Eastern Europe and those of the former Soviet Union through the North Atlantic Cooperation Council (NACC) and the Partnership for Peace (PfP) program. Recently, an additional program, Cooperation Partner (CP) nations has been implemented. Many of the same nations belong to both the PfP and CP programs.

Twenty-six states have accepted the invitation to participate in the NATO Partnership for Peace program. Four of these countries – Austria, Finland, Malta, and Sweden – are not members of the NACC, nor are they CP participants, but they do participate in NACC deliberations on PfP issues and take part in other NACC activities as observers.

One of the mechanisms for increasing ties with CP countries is the ARW program, which requires that meetings be held in CP countries. Another program has been inclusion of PfP states in some of the activities of the GENMED and RADHAZ Working Parties. At these meetings, PfP nations and NATO member nations have exchanged NIR safety standards in the effort to increase communication, scientific information exchange, and in preparation for possible admittance into NATO become more informed on NATO Standardization issues.

Clearly, NATO has a long history of continuing support for scientific investigation into fundamental biological effects of exposure to RFR. This support of research and standardization contributes significantly to the global approach to standardization. Many STANAGs have provided foundation for European Community standardization. There is an increased attention at NATO for standardization to provide increased harmonization. With expansion of NATO and new collaborations with other international organizations concerned with health

and safety issues such as the World Health Organization, NATO has become an important mechanism in facilitating international scientific research, data exchange and global harmonization of NIR standards.

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AN OVERVIEW OF THE EXPOSURE ASSESSMENT METHODS FOR ELECTROMAGNETIC RADIATION

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Introduction

One of the main problems in electromagnetic biology and epidemiology is the metrology. There are few standards in the world describing methods for measurement and exposure assessment of electromagnetic radiation on the workplace.

The methods for measurement and hygienic assessment of the parameters of the electromagnetic field (EMF) are not standardized although the different countries apply devices with similar construction and principles of measurement, as well as similar control methods. This is a reason for discrepancies and contradictory results from some epidemiological studies.

Currently, there are different standards containing methods for measurement and assessment of EMF as well as requirements to the measurement equipment, such as ANSI C.95.1. In Bulgaria such standards are BNS 14425-90 and BNS 17137-90. More details on the methods for measurement could be found in literature, and not in the standards.

In general, the methods used for measurement and assessment could be divided in two groups:

1. **Spot methods** - based on single measurements of the EMF parameters at the assessed work place and men's residences. These methods can be applied if the values of the EMF are comparatively stationary during the work shift (working hours). The hygienic assessment is elaborated based on the maximal measured values or after statistical analysis. They can be applied by dosimetric approach as well - additional processing of the results aiming to assess the exposure and energetic characteristics.

2. **Dosimetric methods** - they comprise personal dosimetry during the work shift or an assessment of the energetic loading of the organism;

determination of the real duration of exposure; measuring the intensities or power densities of EMF with exposure assessment.

One of the most popular methods in the world for assessing the environmental factors is the method of TWA (Time Weighed Average).

Methods and discussion

Here we present standardized methods, applied in the National Center of Hygiene, Medical Ecology and Nutrition at the Ministry of Health (NCHMEN) in Bulgaria for exposure assessment of electromagnetic radiation. These methods are divided into groups as follows:

A. Methods for assessment of electromagnetic emission of different types of sources, like:

- microwave ovens;
- video display units (VDU's);
- broadcasting and other communication objects emitting electromagnetic radiation in residential areas, etc.

B. Methods for exposure assessment of electromagnetic radiation on workplaces with different sources mentioned above and also others in physiotherapy, high voltage substations (open and closed distribution centers) and transformer stations.

1. Method for studying the electromagnetic radiation of microwave ovens for household and similar use.

The method concerns studying of the electromagnetic radiation and verification of the compliance with the requirements of: BNS 63/2 (25), corresponding to IEC 335-2-25 - Safety of household and similar electrical appliances, part 2: particular requirements for microwave ovens.

Estimated parameter: power density of the electric radiation S [W/m^2] for a fixed frequency f = 2450 MHz or f = 915 MHz.

Measuring devices: HI 1501 and HI 1600.

Measurement principle: Spot principle of measurement. The measurements are performed at 5 cm from the external surface of the microwave oven, detecting points with maximal flow of electric power.

2. Method for studying and assessment of the electromagnetic radiation of VDUs

It determines the procedure of measuring and assessment of electromagnetic radiation from VDUs and the possibility for them to be used in the country.

Standard: MPR II - emission standard, Sweden.

Estimated parameters: electric field strength E, [V/m] and magnetic flux density B [mG].

Measuring devices: HI 3604 and HI 3603.

Measurement principle: The measurements are frequency non-selective by using spot method of measurement, reporting the maximal records of the devices at several points: at 10 cm from the external surfaces of the VDU and at 50 cm; after that the measured values are compared to the background in the premise. If a protective screen is used, its effectiveness for screening for both components of the field is assessed.

The methods for studying and assessment of electromagnetic radiation at work places differ from those used for emission assessment by the used regulations, besides MPR II the following ones are used:

- Ordinance N 41. of the Ministry of Health, 1995 for the unified rules for ensuring healthy work conditions;

- Ordinance N8 of the Ministry of Health, 1996 for the hygienic requirements to work places with VDUs.

The measurement principles are the same, but combined with additional measurement of the operator's work place if it is at a distance, different from 50 cm. The measurements are performed in air-equivalent environment without an operator present there.

3. Method for determination of hygienic safety zones around objects, emitting EMF in residential territories.

The method concerns calculation of the field strengths and flux densities of EMF energy in the environment, determination of hygienic protection zones around emitting objects, working within the range 30 kHz - 30 GHz.

Regulation: Ordinance N 9 of the Ministry of Health and Ministry of Environment for Maximal admissible levels of EMF in residential territories and determination of hygienic protection zones around emitting objects.

It is used at calculation of hygienic safety zones at designing stages by the characteristics of the project documentation. The maximal distance along the maximal radiation direction to the point at which the EMF of the aerial decreases to the maximal admissible levels for the respective frequency range is also calculated. When within the margins of this distance there are residential buildings, the EMF of the aerial is calculated for each building (at roof height and along the aerial direction).

After commissioning the object, the electric field parameters are measured: electric field strength E, [V/m] for the range 30 kHz - 300 MHz and power density of electromagnetic radiation S [W/m^2] for the range 0.3 - 30 GHz.

4. Method for studying and assessment of electromagnetic radiation at work places in physiotherapy and rehabilitation cabinets.

It determines the procedure for studying the electromagnetic radiation of devices in wards for physical therapy and assessment for compliance with hygienic standards.

Regulations:

- Ordinance N 41 of the Ministry of Health for ensuring healthy work conditions.
- BNS 14425 - 90 Labor protection. Radiofrequency electromagnetic fields,. Admissible values and requirements for control.
- BNS 17137 - 90 Labor protection. Microwaves. Admissible values and requirements for control.

The method concerns the following types of sources applied in physical therapy and used measuring devices:

- devices for magnetic therapy - HI 3604;
- apparatuses "D'Arsonval" - NFM-1;
- devices for UHF therapy - NFM-1 and RAHAM;
- devices for microwave therapy - RAHAM and HI 1501.

Estimated parameters: electric field strength E, [V/m] or power density of the electromagnetic radiation S [W/m^2].

Measurement principle: Point's measuring method. The points for measurement of the listed devices are as follows: at distances 20, 50, 100 cm from the electrodes, this distance for UHF therapy devices being determined along the perpendicular to the axis connecting the two electrodes; for a MW radar - along the perpendicular to the long axis of the bed (the radar electrode is pointed to the patient's bed) and at 100 cm the measurement is at the level of the head. After those measurements, the distance to the source is evaluated, at which the EMF values are equal to the maximal admissible ones. Measurements for assessment of the effectiveness of screening of the protective chamber are also considered.

5. Method for studying and assessment of electromagnetic radiation at work places in high voltage substations (open and closed distribution centres) and transformer stations.

Regulations:

- Ordinance N 41 of the Ministry of Health for ensuring healthy work conditions.
- BNS 12.1.002 - 78 Labor protection. Electric fields from currents with industrial frequency at 400 kV and more. General requirements for safety.

Estimated parameters: electric field strength E, [V/m] and magnetic flux density B[mG].

Measurement principle: Spot measuring method. The measurement points in open distribution devices are as follows: under rims - at pathways at points of rims connection; for switchyards - at pathways by switchyard for transformers - at 50 cm from the fences. In all cases the measurements are remote at 180 cm height from the earth.

The points for measurement in closed distribution devices are as follows: along the pathways at 50 cm from the protective screens (chambers) and at 150 cm height from the floor in places with established maximal magnetic flux density values.

The measurement points in command halls are: at the operator's work place, in front of the control boards at 20 cm from them and at 150 cm height from the floor and in front of the control devices, in both cases the measurements are at points with previously established maximal magnetic flux density values.

The measurement points in transformer stations are: in front of the transformer, in front of high voltage devices, in front of low voltage devices and background measurements.

6. Method for studying and hygienic assessment of a constant magnetic field in the working environment.

The method specifies the procedure for measurement and hygienic assessment of a constant magnetic field in the working environment according to the requirements of Ordinance N 41 of the Ministry of Health, 1995 for the unified rules for ensuring healthy working conditions.

Estimated parameters: magnetic field strength H, [A/m] or magnetic flux density B [mG].

Measuring devices: magnetometers - "Teslameter".

Measurement principle: The magnetic field is measured at the places with such a field and with temporary or permanent presence of staff. At the selected points the parameter of the field is measured at three levels: at the head, breast and genitals. In the case of local radiation the measurements are performed on the localized area. In the case of measured values close to TLV, the non-homogeneities of the field are determined at 20, 40, 60, 80 and 100 cm from the source.

Principally the methods for assessment of the sources of electromagnetic radiation differ from those for their measurement at the work places by the selection of points for measurement and by the procedure. Naturally, the standards used for the assessment are also different.

The equipment available at the National Center of Hygiene, Medical Ecology and Nutrition is used for the proposed methods. At present, the qualities of the equipment for such measurements are studied.

The methods have been practically standardized in the whole country.

Conclusion

The further activities for creation and unification of methods for measurement and assessment of electromagnetic radiation should be oriented towards comprising more typical sources and work places near such sources. The NCHMEN considers the development of the following methods:

- **for emissions** - production equipment for high frequency processing of materials (plastics, metals); electric medical devices, nuclear-magnetic resonance equipments, machines for induction heating of metals, for electric erosion, for thermal processing of dielectrics, electric welding machines, sources of electrostatic fields

- **for work places** - in communication systems, in electric vehicles and at work places with the listed sources.

Regulations for optic polychromatic and laser radiation are elaborated in the same way.

The equipment available in the NCHMEN is used. At present its qualities at such measurements are studied.

The main goals for creating and unification of the methods for measurement and assessment of electromagnetic radiation are:

- comparability of the results from studying sources of similar type and possibilities for their use in epidemiological studies;

- use of the collected data from measurements for creation of information systems and data bases and their further application for assessment of the risk and impact of EMF;

- possibility for checking the hygienic normative criteria.

References:

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2. BNS 17137 - 90 Labor protection. Fields, electromagnetic microwave. Admissible values and requirements for control.

3. BNS 12.1.002 - 78 Labor protection. Electric fields from currents with industrial frequency at 400 kV and more. General requirements for safety.

4. BNS 63/2 (25) - Safety of domestic and similar electric appliances, Part 2: Specific requirements for microwave ovens.

5. Ordinance N 41. of the Ministry of Health, 1995 for the unified rules for ensuring healthy work conditions;

6. Ordinance N8 of the Ministry of Health, 1996 for the hygienic requirements to work places with VDUs.

7. Ordinance N 9 of the Ministry of Health and Ministry of Environment for Maximal admissible levels of EMF in residential territories and determination of hygienic protection zones around emitting objects.

8. MPR II - emission standard, Sweden.

FUNDAMENTAL CONTROLS FOR SOURCES OF ELECTROMAGNETIC FIELDS IN THE ENVIRONMENT

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Electromagnetic fields (EMF) of various frequencies in the environment are generated by both natural sources as well as artificial (anthropogenic) sources.

Natural EMFs arising from the myriad of stars and other celestial phenomena, penetrate and fill outer space including the space surrounding the earth (extra-atmospheric and intra-atmospheric space) since electromagnetic waves can propagate through various material media and in vacuum.

Some atmospheric phenomena (ionospheric, stratospheric and tropospheric), natural processes occurring on the earth's surface and within the earth (vulcanism, earthquakes etc.) are also natural sources of EMFs on earth. All of these natural sources comprise the natural radiobackground of the earth which has always existed and within which there can be distinguished, monitored and evaluated a regular and an irregular (chaotic) component.

Since the end of last century and especially in present century, EMFs from various artificial, man made sources have been added to this radio background. The most predominant of all these sources are specially created radio communication facilities, radar, radio control etc. sources generating EMFs which are deliberately radiated into space and having transmitting antennae for this purpose.

Besides this, anthropogenic sources of EMFs include a variety of electrotechnical equipment used for the generation, transmission, and transformation of electrical energy. Such equipment is designed not for radiating EMFs, which in such cases is an undesirable but nevertheless unavoidable accompanying phenomenon for which the transmission lines, transformation appliances and so on serve as the "transmitting antennae."

Considering that today it is universally recognized that EMFs are biologically (including physiologically and medically) not insignificant for humans, while the sensitivity and nature of the reactions for EMFs of different frequencies varies over wide ranges (from beneficial to unfavorable and even to pathological), it becomes essential to control EMF sources not only in the environment in general but also in the immediate habitational and occupational surroundings of human activities.

For these purposes we incorporate into the meaning of the word "Control" not only concepts like "calculation, verification, observation" (monitoring) assumed in the Russian language, but also those envisaged by the English language interpretation of this word such as "management, restraining, control" of EMF sources.

In a broader hygienic sense, the meaning of "Control of EMF sources" should be understood generally as the protection of humans from the unfavorable effects of EMFs emitted by such sources.

As far as natural sources of EMFs mentioned above are concerned, at the present stage of scientific and technical progress, mankind cannot control them. That is why control of such sources consists only of keeping vigilant watch on the levels and dynamics of EMFs of natural origin for the purpose of studying these phenomena, and also their forecasting and informing communities about them to permit their taking possible organizational, behavioral or medical preventive measures against unfavorable meteotropic reactions among people who are sensitive to this factor. This area of electro-magnetobiology and hygiene is not presently adequately developed. However it appears to be important and interesting and that is why it deserves greater attention among researchers who are dealing with low intensity factors.

The matter stands differently with anthropogenic, artificial sources of EMF. Being a product of the human brain and human hands, such sources must and can be controlled by people.

The basis for such controls in our country resides in the Russian Federation's law "On the Public Health - Epidemiological Welfare of the population", which stipulates an obligatory implementation of state public health supervision over the design, construction and operation of radio engineering units and electrotechnical systems representing sources of EMFs.

The most important system defining kernel of such supervision is the observation of hygienic standards which are officially established for permissible levels of irradiation of people for the different frequency ranges of EMFs. Resulting from these standards, various protective measures are developed and applied, amongst which there must be distinguished active and passive measures.

In a literal sense, active measures represent control of a radiation source by influencing it in an hygienically favorable manner by introducing changes to its technical and operational characteristics.

Passive measures do not exert any direct influence on the characteristics of an EMF source but provide for a reduction of their level over a zone and, as a result, a reduction of the irradiation of people.

Resulting from these considerations, in practice, for controlling the irradiation of the population, the following points should be addressed and implemented:

- organizing public health protective zones near radiating objects and limited construction zones in the area of their influence;

- implementing engineering technical and organizational measures on objects themselves i.e. on the EMF sources;

- carrying out planned, constructional and engineering technical protective measures outside the objects - principally sources - within the area of the public health protective zones and restricted zones.

An essential condition for organizing efficient control of the EMF sources is a compulsory counting and registration by the state of the objects which are radiating EMFs into the surrounding environment. This counting and control must begin at the preventive public health control stage; already at the time when consideration is being given to the feasibility of projects accommodating radiating objects, the location, within their zone of influence, of residential buildings, on selecting and rejecting of sites for their construction, and also in the course of construction and acceptance into operation.

As it was indicated above, an important means for the control, management and limitation of the unfavorable influences of anthropogenic sources of EMF is the organizing of public health protective zones and limited building zones in the areas adjacent to radiating sources.

The external border of the first zone, being simultaneously the internal border of the second, must be established on the basis of the MPL for the corresponding EMF measured at a height of 2 m above the surface of the earth. Thus within the boundaries of the public health protective zone of a radiating object, the MPL can be exceeded at the surface of the earth itself, whereas in the limited building zone this excess is allowed only at a height of 2 m or more from the surface. The external border of the protected zone is established according to the maximum height of the buildings possibly to be constructed in this area, where

at the level of the topmost floor, the magnitude of the EMF must not exceed the MPL.

Thus protection against EMF by means of public health protective zones is based on the distancing of the protected people from the source i.e. it is a passive measure.

Among the active measures of controlling EMF sources are engineering-technical and organizational measures applied to the objects, such as: increasing the height and working angle in the installation of an antenna, establishing restricted sectors for their operation as emitters, transfering the object to another place, etc. Protective engineering-technical measures, which are applied external to the object - EMF source - take on a sort of intermediate character between active and passive measures. On the one hand, they generally do not reduce the irradiation of the surrounding environment by the electromagnetic source, but, on the other hand they protect people from irradiation in specific areas of the adjoining territory. To the list of such measures belong: installation of protective screens, application of radio-protective materials, shelters, town planning and siting decisions.

The full-fledged and efficient control of EMF sources requires the obligatory application of the noted measures of preventive public health management through the routine undertaking of ongoing inspection measures. Ongoing public health inspection for EMF sources assumes, first of all, the tracking (monitoring) of the existing electromagnetic situation created by the corresponding radiating objects, the analysis and correlation of such data, and also the collection and processing of information about the possible influence of EMFs on the condition of peoples' health. In the course of ongoing public health control there must be carried out inspections to ensure the implementation and effectiveness of protective measures provided by the project and also additional desirable protective measures.

The major problem of ongoing public health inspections of the electromagnetic situation in places people live for extended periods of time, is the control of so-called secondary EMF sources which arise as a result of the re-emission (reflection) of electromagnetic energy by objects situated in its path. The nature of the secondary radiation and reflection of electromagnetic waves depends on the form of the object, its size and electrical characteristics, and also on the wavelength of the incident wave and its polarization.

When the wavelength is large compared to the dimensions of the object, the incident wave bends around it and the reflected wave is smaller. The shorter the wavelength, the more likely will be reflections of a diffusive nature.

If the linear dimensions of the reflecting object are equal to odd numbers of halfwaves, resonant reflections of the EMFs will be observed. Unlike diffuse reflection, secondary resonant radiation usually possesses a much greater intensity, depending on the configuration and orientation of the reflecting element of the object.

In close proximity to the re-emitting elements, such as metallic or metal coated structures (wires, pipes, childrens' playground equipment, metallic scaffolding, lifting cranes, power transmission line supports, etc.) the resulting EMF which occurs can considerably exceed the intensity of the incident wave, as far as intensity is concerned. Thus, the electromagnetic situation close to a re-emitting element can considerably differ from that which is observed only a few metres away from it up to an amount significantly in excess of the MPL for the EMF.

From a hygienic point of view, an unfavorable factor in these situations for people, apart from the amplified EMF intensity itself, is the induced EDS (electromotive force, emf) which gives rise to the risk of injury from electric current.

This phenomenon is particularly notable within the range of short, medium and long waves. In the apartments of apartment buildings situated close to such radio stations, the EMF levels near heating radiators, refrigerators, telephones and other similar objects, can be several times (sometimes ten times) greater than outside the building at the same height. In this connection, the control of EMF sources should also be extended to re-emitting elements which also requires implementation of specific protective measures. Thus, in the zone where radio stations have such an influence, it is not recommended to use baby rockers, rocking chairs, other playing devices, fences, etc., made of metal. Under these conditions, wood, bricks and other similar materials, which do not conduct electricity, should be used. The remaining metallic structures and metallic roofs must be securely grounded according to high frequency practice which can significantly reduce the level of EMFs in the premises.

A separate problem is represented by the control of EMF sources of extremely low frequencies which includes electric power distribution lines. The intensity of EMFs under the lines depends significantly on the wire suspension

heights, the distance between them, the voltages and strengths of the current passing through them and the relief and plant cover under them. Control of these EMF sources is based on adherence to corresponding standards of construction and laws which fulfil the hygienic requirements.

From what has been presented above, it is possible to formulate the following basic principles for controlling EMF sources and providing safety from them to the population:

1. The control of EMF sources must include not only the observation of the electromagnetic situations within their zone of influence, but also the interactions of such sources with the goal of reducing any unfavorable consequences of the radiation.

2. As a basis for evaluating the electromagnetic situation in the surrounding environment, in populated areas, for producing, developing and implementing protective measures, there must be applied hygienic standards which are officially established and scientifically grounded - maximum permissible levels (MPLs) for EMFs of the corresponding frequency ranges.

3. The essential condition for providing safety to people in zone of influence irradiated by radio-technical and electrotechnical objects is the steadfast observance of the corresponding MPL for EMFs.

4. Public health measures in programmes for controlling EMF sources must be directed both toward carrying out any necessary engineering-technical work on the radiating objects themselves and also toward implementing established protective measures of a planned, constructional and engineering-technical nature external to such objects - over the grounds of industrial enterprises and around residential buildings as well as directly inside residential, communal and production premises.

METHODS FOR THE PREDICTION AND MAPPING OF EMFs FROM TELECOMMUNICATIONS EQUIPMENT IN THE ENVIRONMENT

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The electromagnetic hazards associated with the equipment used for radio communication, radio and television broadcasting. The operation of equipment used for radio communication, radio and television broadcasting covers virtually all of the radio frequency region of the spectrum. The characteristics of radio wave propagation, the specifics of the design and placement of antenna-feeder structures, and the regulatory principles applied to electromagnetic fields (EMFs) as a factor having negative effects on the environment make it necessary to analyze the public health-hygiene and ecological hazards constituted by this equipment operating in the various frequency ranges.

The sources of low and medium frequency radiation constituting a threat to the environment are mostly used for radio broadcasting (in Russia low and medium frequency ranges are used for broadcasting very extensively). A low and medium frequency broadcasting network covering the whole country has been fully implemented by now. The network is being further developed only by way of increasing the radiation power and efficiency of the transmitting antennas. The radiation power of the equipment currently used for low and medium frequency broadcasting can be as high as 1,000 kW and sometimes even higher. An important characteristic of low and medium frequency waves is that they travel along the surface of the Earth (therefore they are called surface waves). The main requirement for the systems producing surface waves is that they have maximum gain along the horizon. Naturally, when this feature is combined with high radiation power, low and medium frequency radiation presents a serious danger for the environment.

Equipment operating in the high frequency range is used both for radio broadcasting and for long distance radio communication. The transmitter power can reach 200 to 250 kW. Antennas used for this frequency range vary significantly in size and types. Over 100 different designs are currently available, including some antennas and antenna systems of very high efficiency (they have narrow-beam distribution patterns and high gain values). Propagation of high frequency radio waves in most cases involves their reflection from the ionosphere (therefore they are called ionospheric or space waves). Surface waves of high

frequency range also exist. However, they can only travel over a short distance from the source of radiation, due to the high level of their absorption by semiconducting soils.

High frequency radio links can only be reliable when the distribution pattern of the transmitting antenna in the vertical plane provides for the maximum gain in the sector of elevation angles between 2 or 3 degrees (the lower border) to 20 degrees (the upper border). This sector corresponds to the sector of the most probable angles of arrival at the receiving antenna. Analysis of the electromagnetic situation shows that both ionospheric waves and surface waves are dangerous for the environment. While ionospheric waves give rise to limitations on the height of the objects for which the radiation levels are regulated, surface waves limit the boundaries of the danger zone.

In the telecommunications industry high-frequency transmission equipment units form complexes. The operational modes of individual units are subject to daily and seasonal variations. This leads to ongoing changes in the electromagnetic situation and consequently makes the electromagnetic monitoring process very complicated.

Historically complexes of low, medium and high frequency transmitting equipment have usually been situated outside of residential areas. However, the rapid growth of cities, towns and villages, including the special settlements built for the personnel maintaining such complexes, has created widespread infringements of the ecological conditions with regard to the factor of EMF hazard in populated areas.

Due to its location and modes of operation, television broadcasting equipment is recognized as another source of "electromagnetic pollution" for urban areas. Here are some factors that make television and FM radio broadcasting equipment dangerous for the environment: their location within the centres of densely populated areas, several radio and TV programmes are broadcast on different channels at the same time, antennas are placed on high towers and oriented so as to cover the service area including the neighborhood of the broadcasting station, the radiated power level of each unit is quite high (from several kilowatts to 50 kW), a lot of broadcasting is carried within the VHF and UHF ranges where EMFs have their strongest biological impact.

The rapid development of cellular mobile communication networks has been accompanied by a massive increase in the number of base stations, which are usually located in the most densely populated regions of cities in residential areas.

The maximum power levels of the transmitters at base stations are comparatively low (they do not exceed 100 W). However, quite often the antennas of such stations are mounted on the roofs of apartment buildings or in immediate proximity to them. Therefore, in recent times, base stations of cellular mobile communication systems are now closely studied by health protection and environment protection services.

The principles of numerical prediction of the electromagnetic fields near emitting equipment. Pre-estimation of the electromagnetic situation around emitting objects is one of the most important tasks of electromagnetic ecology. This task should be carried out while the radiating objects are being designed, installed or remodeled. This permits the electromagnetic situation to be evaluated from the point of view of complying with the existing regulations [1,2] by taking appropriate steps and actions in the process of city planning. Besides this, with good estimates it is also possible to evaluate the prospects for the development of existing centres of telecommunication, justify the possibility of increasing the radiated power and the antenna gain of the transmitting equipment, and find the optimal locations for the antenna systems. The precalculated EMF levels and danger zone boundaries are registered in the sanitary passport of any radiating object.

The initial placement of radiating objects should always be preceded by the careful application of electromagnetic expertise based on the calculation of EM fields. The boundaries of danger zones for equipment currently in operation are "first determined by means of calculation and then defined more precisely by measurements" [2]. Such an approach to the application of electromagnetic expertise to emitting objects is justified by the fact that if the the full scope of measurements were to be taken, with the processing of the results, the process would be extremely laborious and would simply not be feasible.

The methods for pre-estimation have to be reliable, scientifically well-grounded and approved. Their description should become part of the public health regulations. For the equipment used in wireless communication and radio or TV broadcasting the development of such methods can be very difficult due to the wide frequency range of the equipment, the diversity of placement conditions and the wide variety of radiating systems used. Nonetheless, the task has been successfully carried out for virtually all types of telecommunication equipment and, as a result, a series of state methodological documents has been published [3,4,5,6].

Due to the intricacy of EM field structures near sources of low, medium and high frequency elecromagnetic waves, and due to the large number of factors influencing the fields, it is rather difficult to estimate fields in all these frequency ranges. The indicated complexity was dealt with by the careful aplication of a set of precise solutions to fundamental electrodynamical problems such as the problem of a simple dipole radiating in free space and also elementary dielectric dipoles in a two-layer medium.

In designing equipment that generates electromagnetic radiation of low, medium and high frequency, attempts have been made to create mathematical models based on a number of assumptions, approximations and simplifications which are valid only for the far-field zone, do not take into account the partially conducting character of the earth's surface, and use manual computation methods. The approximate mathematical models were only applied in a few particular situations, gave results of an evaluative nature, and were of absolutely no use in case of antenna complexes. The research has shown that the complex components of the field, which are critical in determining the electromagnetic environment, can only be calculated by using precise methods.

When sources of VHF and UHF radiation are examined for their impact on public health and the environment, EM fields are usually calculated for the far zone. An exception is made for cases where it is necessary to estimate the environmental impact of the radiation in the immediate vicinity of the source, e.g. on the roof of the building or on the tower where the antenna is mounted and where maintenance people are supposed to work.

The levels of electromagnetic radiation for the far field zone can be calculated from the antenna specifications. This method is described in [2]. It is known from practical experience that technical specifications of radiating devices often do not provide all the necessary information on either the directional characteristics of the antenna (the gain, the directional distribution pattern), or on the antenna feeders. In such cases it is quite difficult, if not effectively impossible, to make a good estimate. Such a situation may occur when it is necessary to estimate near-field radiation levels for specialized equipment installed by foreign companies, for special equipment, for units incorporating non-standard antennas, etc.

For aperture antennas which are used in the UHF and SHF ranges, the field analysis becomes difficult because of the necessity to calculate field levels in the near zone including the area of diffraction behind the aperture. Other factors making it complicated are the variety of amplitude-phase distributions,

peculiarities of the antenna design, and the necessity to account for the radiation from the feed element.

Automation of the calculation process for prediction. A modern radio or TV broadcasting centre is a complex of equipment including a number of antennas of various degrees of sophistication. A big radio centre can incorporate a few dozen antennas. Single sources of radiation are seldom used at radio centres with the possible exception of broad-beam antennas that are used at isolated radio stations. Radio broadcasting centres very often have equipment covering several frequency ranges on site. It is not uncommon to have a situation where HF, MF and LF equipment is present at the same radio centre while in other cases HF equipment is installed in the immediate vicinity of the VHF antenna towers used for radio or television broadcasting. In cities a large number of antennas for various purposes and of various frequency ranges are often found in one place which is convenient for covering large service areas (various high towers, the roof of a tall building, etc.).

The difficulties of analysing the electromagnetic environment at a broadcasting complex are obvious. They are due to a simultaneous operation of a number and variety of radiating objects producing electromagnetic fields of different intensity, polarisation and freqeuncy that depend on the parameters of the underlying ground, and the antennas themselves can be situated in a variety of ways.

Although antenna devices, like the majority of other pieces of telecommunications equipment, are standard for the most part, they are installed or used in non-standard situations. The uniqueness of each source from the point of view of the emited electromagnetic fields arises from the way the individual antennas are positioned and orientated, in the parameters of the ground and the relief of the area, in the schedule of using different parts of frequency spectrum, in the specific set of equipment involved and so on. All this makes it very difficult, if not impossible, to develop one common approach to the analysis of the electromagnetic situation for various objects that include equipment operating in different frequency ranges.

For complex radiating objects with a mixed impact of electromagnetic fields it is virtually impossible to determine the boundaries of danger zones without the extensive use of computers since the process does not only require that the field or the energy flow density should be repeatedly calculated for each piece of equipment, but it also requires that the calculated values should be checked against the standard safety limits.

Mathematical simulation which has been chosen to be the main method of research, is a powerful and probably the only possible method of analysing the electromagnetic situation for a complex of telecommunications equipment. The extensive use of this method for the simulation of EM fields generated by telecommunications equipment has made it possible to create a powerful system for the computer estimation of the EM fields (SCE EMF) which is currently used by the author as a tool to analyze the electromagnetic factors in the environment for the purpose of carrying out the public health and ecological evaluation of such objects.

Computer estimation programs have been developed for various groups of antennas distinguished on the basis of their function, their frequency range and placement conditions.

The first group includes LF, MF and HF antennas, for which the emissions analysis takes into account the electrophysical properties of the underlying ground. These can be dipole and wire antennas. Methods used to calculate the near field are based on finding a precise solution to the radiation problem for a simple dipole situated above a partially conducting boundary, and on the subsequent application of the superposition technique. These calculations are done by numerical methods which provide estimates for the full set of eletromagnetic field components and can be applied to complicated radiating systems.

The second group comprises TV broadcasting antennas and antennas used for broadcasting on VHF with frequency modulation (FM). Since these antennas are positioned high above the ground, the boundaries of their danger zones always lie in the far-field area. For the purposes of electromagnetic ecology it is, therefore, totally sufficient to carry out the analysis of the situation using a two beam model incorporating either the performance characteristics of real antennas, or the obvious relations for different types of antennas.

The third group includes aperture antennas operating in UHF and SHF ranges. Their EM fields are difficult to analyze because of the necessity to calculate the near field including the field behind the aperture. This difficulty is further complicated by the variety of amplitude-phase distributions, the specific character of the antenna design, and the necessity to adjust for the radiation from the feed element.

The SCE EMF has been developed not only as a means to set the boundaries of danger zones and obtain data for public health approvals, but also as a tool with which one can estimate the contribution of each particular antenna to

the electromagnetic situation and also check the electromagnetic situation for compliance with the existing norms and regulations.

At the present time the SCE EMF consists of three independent branches, each designed to estimate the electromagnetic situation of transmitters covering various frequency ranges. Each branch of the SCE EMF has several modes of operation. The user chooses one mode or another depending on the required volume of data for the electromagnetic estimation and on the stage the calculation process is in at the moment. The first mode of operation generates a print-out with a list of the equipment constituting the broadcasting complex, including the location and geometrical parameters of the antennas. The second mode of operation permits the calculation of the field strength generated by the complex of broadcasting equipment for any direction, height and distance interval specified by the user. For each calculated point there is calculated the strength of the field from each antenna and also the summed strength of the field for each frequency region specified in the safety criteria. This mode of operation is especially good for estimating the contribution of each antenna to the overall electromagnetic situation and permits finding optimal locations for the antennas. The third mode of operation permits the calculation of safety limit values for a complex of broadcasting equipment. The magnitudes of the safety limit values is calculated for every direction within a specified sector and for every point within a specified interval of distances. It is mainly this mode that is used for the determination of the danger zone boundaries for the radiating objects.

Mapping the electromagnetic situation. In many cases the ultimate purpose of the estimation process is mapping the EM fields for given sources of radiation. In doing so it is essential to take into account the character of electromagnetic field effects which can be isolated, combined or mixed. In cases of isolated or combined effects it is practical to map the electromagnetic situation as lines of constant field strength. In the case of a mixed effect, which is the most commonly encountered case in the practice of EM field analysis, it is best to map lines with a constant safety limit value to give us an idea of the level of danger in the environment thaking into account the existing safety standards. By contrast, maps of the electromagnetic situation alone are uninformative from the point of view of electromagnetic safety.

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EXPOSURE AND RISK ASSESSMENT OF EXTREMELY LOW FREQUENCY FIELDS IN ELECTRODISTRIBUTION SYSTEMS

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Introduction

Electricians are this part of the staff in all industrial branches related and responsible to servicing power distribution systems. The people who supervise, maintain and repair the high and low voltage installations and transmission lines are the main part of the staff in the electrodistribution system. For this staff group the electric and magnetic fields with power frequency are the main hazardous factor. The time of exposure is the longest - during the whole working shift - usually 8 or 12 hours.

In the last years the extremely low frequency electric and magnetic fields have been considered as one of the possible factors, potentiating the development of some cancer diseases, especially in the presence of other carcinogens or hazardous working conditions [1].

Due to the increased possible risk of cancer the electricians in the electrodistribution systems are considered as a risk staff group in relation to extremely low frequency electric and magnetic fields.

Object of investigation

A working group from the laboratory "Physical factors" of the National Centre of Hygiene, Medical Ecology and Nutrition, has investigated the extremely low frequency fields in the electrodistribution systems in Bulgaria. The object of interest are different kinds of power distribution substations: 750 kV, 400 kV, 110 kV, as well as distribution systems in dwellings.

This report presents the results from our study in:

- open-air distribution facilities 400 kV in the substations "Tzarevetz", "Dobrudga" and "Varna" [2];

- command halls, indoor (20 kV, 6 kV and 1.65 kV) and open-air (110 kV) distribution facilities in substations in "Mines Maritza East", a complex of open-air coal mines [3].

The measurements in the substations "Dobrudga" and "Varna" are performed in 1994 only for assessment of the working conditions and are not very comprehensive. In the report they are used only for comparision with the results from "Tzarevetz" investigated in 1997.

In "Maritza East" we have studied 10 substations with similar construction and designation for reducing the 110 kV high voltage to 20 kV, then to 6 and 1,65 kV, and after that for distribution to cranes in the mines. The investigations are made in 1997, too. Figure 1 presents a principle layout of an open-air distribution device and a list of the substations names with the notes used later in the report.

The places of measurements are grouped as follows:

- **command halls** - the supervising and monitoring rooms inside the buildings;

- **indoor facilities** (20 kV, 6 kV and 1.65 kV) (closed distribution devices) - rooms inside the buildings with screened cases and devices for maintainance and switching the voltage;

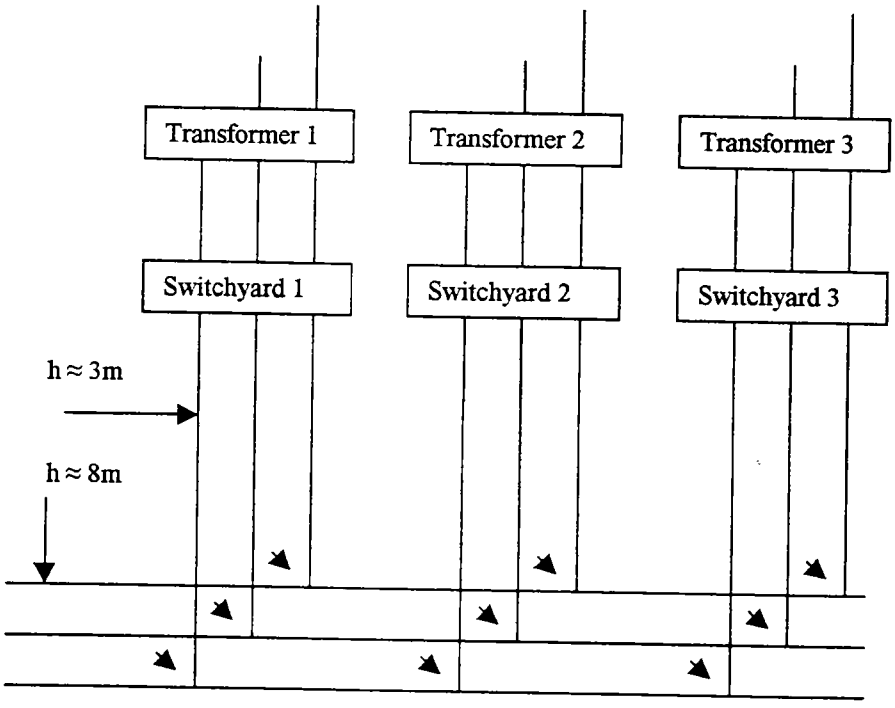
- **open-air facilities** (400 kV and 110 kV) - the systems from rim lines, switchyards, transformers, capacitors and other devices outside the buildings.

Methods

The methods applied for assessment of low frequency electric and magnetic fields are based on the separate measurement of the electric and magnetic components of the field: electric field strength E [V/m] and magnetic field strength H [A/m] or magnetic flux density B [mG]. For exposure assessment it is necessary to evaluate the real duration of the staff exposure at the working places [4].

We performed single or multiple spot measurements around different sources to determine the places with the greatest radiation values. In the open-air distribution facilities the measurements are made only at the pathways for supervising or at the platforms for control. In the indoor distribution facilities and

command halls the measurements are performed at the places of the operator on duty and in front of the control tables.



Note	Substation	Note	Substation
5	5	N	North
6	6	W	West
7	7	E	East
8	8	T	Third march
S	South	B	B-2

Fig. 1. **Scheme of the open-air distribution facility in substation 5 of Mines Maritza East**

The equipment applied for measuring the extremely low frequency electric and magnetic fields is the frequency-non-selective measuring device HI-3604 of the firm "Holaday Industries" produced 1994. The frequency range covers 20 ÷ 2000 Hz for the electric field and 20 ÷ 1000 Hz - for the magnetic. The error of the device is ± 30%. The measurements are made by placing the measuring sensor such that incident field lines strike the sensitive plate at angles as it is sited in the operations instruction.

The hygienic assessment of the measured electric and magnetic fields is performed according to the following regulations:

- Ordinance No. 41/1995 of the Ministry of Health for Unified Rules for Healthy Working Conditions, which corresponds to TLVs of ACGIH [5];

- BNS 12.1.002 - 78 Occupational safety. Electric fields from currents with power frequency [6].

In the places where the measured values exceed the norm it is necessary to determine the permissible time duration for the staff without special protective clothes or other safety measures corresponding to the requirements of BNS 12.1.002-78.

Risk assessment is based on the *"Risk Rating" method*, using the exposure assessment values and the morbidity with temporary disability data studied for the different groups [7], as it is described later.

Results and discussion

The values of the electric field strength in the open-air facility in substation "Tzarevetz" following the order of conducting of the measurements are given on fig. 2. The results are grouped depending on the designation of the devices:

- **rim lines;**

- **switchyards;**

- **transformers;**

- **screened areas.**

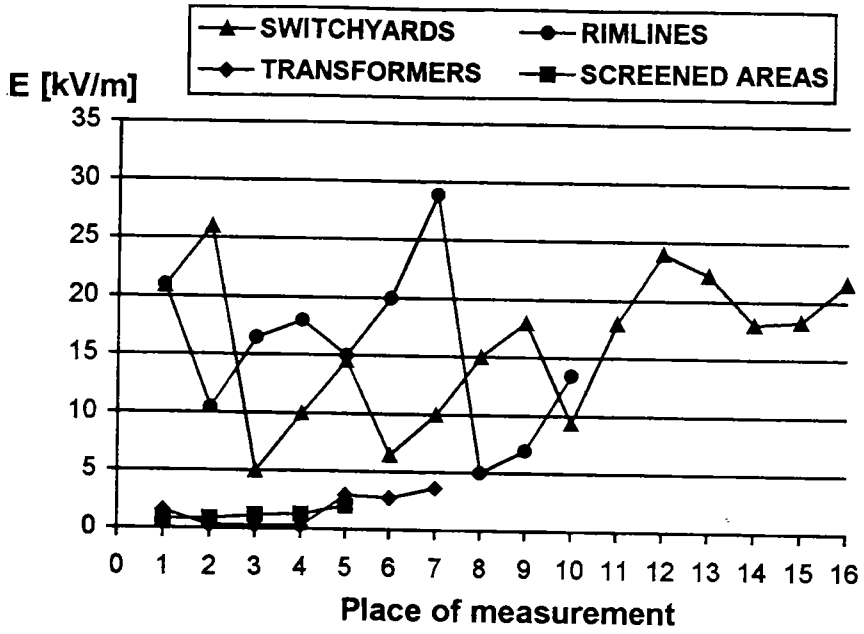


Fig. 2. **Measured values of the electric field strenght in substation Tzarevetz**

The values in the groups of rim lines and switchyards are in the range from 5 to 30 kV/m. They exceed the norm for unlimited stay of the staff and at that places it is necessary to determine the maximum permissible time duration [6]. At places with measured values above the threshold limit value for power frequency (25 kV/m) the stay of the staff without protective clothes [6] is prohibited.

The measured values in the groups of transformers and screened areas are lower than in the other proups and are below the hygienic norm (5 kV/m). Consequently, the screens protect the staff to a satisfactory degree.

A similar tendency is confirmed also by the results from the measurements in substations Dobrudga and Varna, as it could be seen from the presented average values (Fig.3). In the transformer group of substation "Dobrudga" the average value differ significantly from the others. The possible reason for this is the incorrect joining of some of measured points to this group of the conduction of the measurements at a closer distance from the devices.

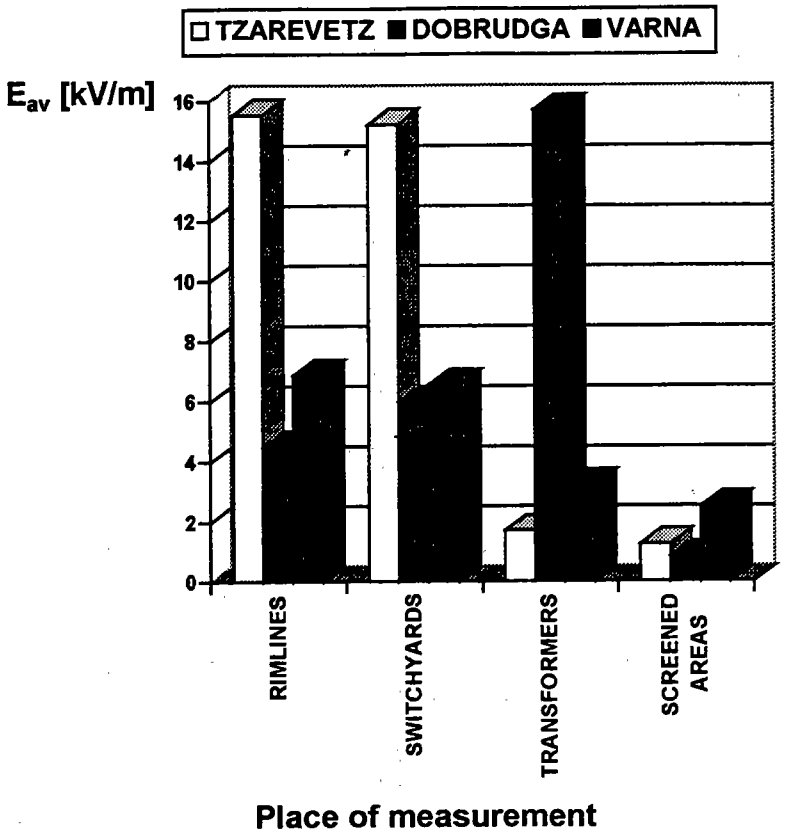


Fig. 3. **Averaged values of the measured electric field strenght in substations 400 kV**

Figures 4 and 5 present the results of the measurements in "Maritza East Mines" grouped by:

- **open-air facility;**
- **indoor facility;**
- **command halls.**

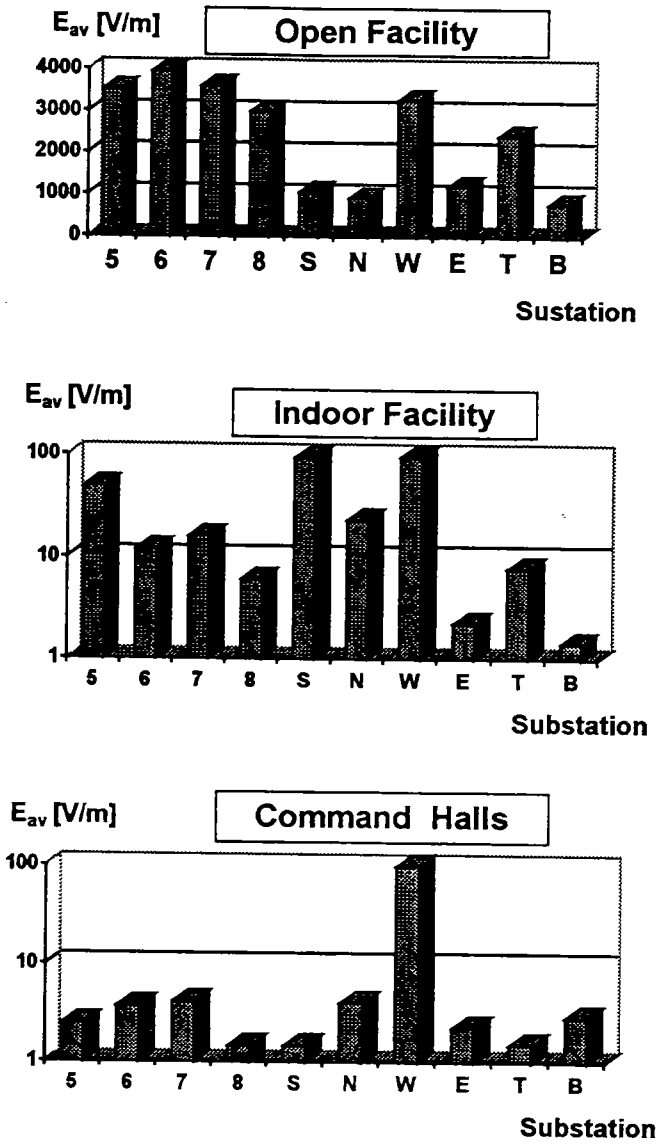


Fig. 4. **Averaged values of the measured electric field strenths in substations of Mines Maritza East**

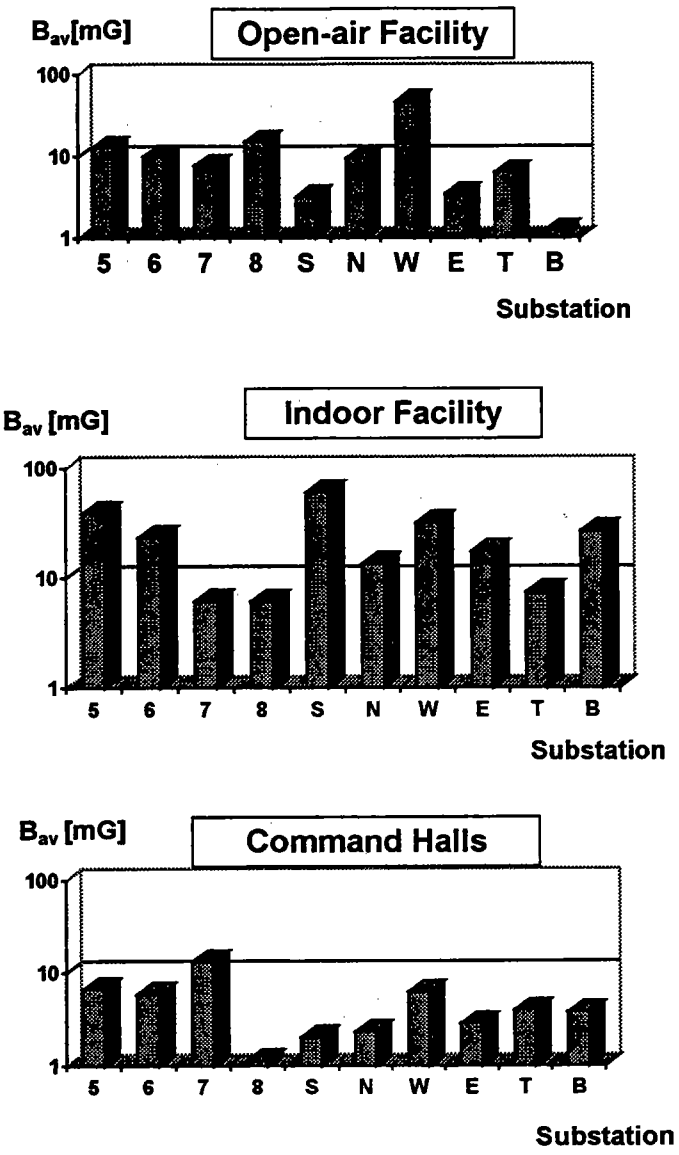


Fig. 5. **Averaged values of the measured magnetic flux densities in substations of Mines Maritza East**

In the group of the open-air facilities the average values of the measured electric field strengths are in the range between 0.8 and 4 kV/m and lie below the hygienic norm for working environment [6]. The lower values as compared to substations Dobrudga and Varna are due to the lower voltage used (110 kV).

In the groups of the indoor facilities and command halls the averaged values of the measured electric field strengths do not exceed 100 V/m. This is a value typical even for residences and does not exceed the hygienic standards.

The averaged values of the measured magnetic flux densities do not differ significantly among the different groups: open-air facilities; indoor facilities and command halls. A probable reason of this is that the magnetic field values depend on the electric current (energy consumption), and not on the voltage of the lines. All measured values correspond to the cited hygienic standards for the power frequency - 12 G, also for people with implanted cardiostimulators - 1 G [5].

Risk assessment is based on the "Risk Rating" method, using the exposure assessment values and, also, the morbidity with temporary disability data for the different groups [7]. A risk rating is calculated thus:

RR = P (Probability) * S (Severity) * F (Frequency),

which gives a range of risk between 1 and 1000. Standard Probability, Severity and Frequency are defined in scales from 1 to 10 [7].

For the studied group in "Dobrudga" and "Varna" the probability index is P = 7 ("Probable"), defined by EPA (Environmental Protection Agency) in 1992. The severity index is S = 4 ("Absent from work for more than 3 days but less than 3 weeks with subsequent complete recovery"). The frequency index is F= 6 ("Hazard arises every hour").

The calculated risk rating is RR = 168 for the group of operators, and RR = 126 for the other staff of the substation [2].

For the staff in Mines Maritza East the risk rating is calculated in the same way and the result is *RR = 140* [3].

These calculated values give a priority of actions in respect of risk *"No immediate action necessary, but keep under review"* [7]. When we take in account the number of the staff at risk (401 studied persons in substation Dobrudga, 466 in

Varna and 153 in Mines Maritza East) the priority of action becomes *"Action within next month"*.

Conclusion

In relation to the groups of facilities the measured values depend strong of the used voltage. In the open-air facilities of substations 400 kV the values are significant and there are investigated more places grouped by the devices. It is determined the tendency that the measured values in the groups of devices "rim lines" and "switchyards" exceed the norm for unlimited stay of the staff. The measured values in the groups of "transformers" and "screened areas" are lower than in the other groups and they are below the hygienic norm.

In the group of "open-air facilities" in substations 110 kV the averaged values of the measured electric field strengths do not exceed the hygienic standard for professional exposure and in the groups of the "indoor facilities" and "command halls" the values are typical even for residences.

At the places where the measured values of the electric field strength are above the norm it is determined the maximum permissible time duration for the staff without protective clothes.

The measured magnetic flux densities do not differ significantly among the different studied groups and correspond to the cited hygienic standards which do not consider the potential carcinogenic effects of extremely low frequency magnetic field.

The calculated risk rating for the investigated staff shows the need of continuous monitoring of the electromagnetic factor, and a special medical care for the people.

Extremely low frequency electric and magnetic fields can influence and provocate some diseases of the cardiovascular and vegetative nervous systems. Then it is necessary to perform precise selection of the staff engaged with electricians' jobs.

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EVALUATION OF THE ELECTROMAGNETIC FACTORS AFFECTING HUMANS DURING HIGH VOLTAGE EQUIPMENT MAINTENANCE

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The following electromagnetic factors act upon a human situated in the vicinity of a high voltage installation (HVI): commercial frequency (CF) electric fields (EF) and their associated air-ion and capacitive currents, CF magnetic fields (MF) and also broad-band fields (BBF) from electromagnetic radiation (EMR) associated with corona discharge (CD) along the phase wires of the line. Studies have been conducted with the objective of determining the degree of influence of these electromagnetic fields on humans and the development of means for protection and reduction of the levels of effect of these factors..

Systems for measuring the levels of effects on humans by electromagnetic factors associated with high voltage installations

1. **System for measurement of capacitive currents in the parts of human body situated in CF EF generated by HVI.** It is done as a life-size mock-up of an erect human (MEH-1) coated with two layers of brass foil and electroconductive epoxy paint with the average conductivity of human body. There are 10 measurement zones in the mock-up (fig.1): head, trunk, two shoulders, forearms, pelvis, right leg, left thigh, left shin and foot. The device is provided with a portable control unit with an arrow displaying measurement results. Was used for checking the screening effect of special clothes protecting humans from EF, and the protective clothes were found to be highly effective.

Fig.1. MEH-1 system **Ph-1 type**

2. **MEH-2 system for measurement of the EF strength (E) distribution over the human body surface.** This system, like the ones of the same type that followed it, is reinforced

from within by a coating of glass fabric and epoxy tar, and on the outside it is coated with two layers of brass foil and electroconductive epoxy paint. Is provided with 82 capacitive measuring electrodes placed at acupuncture points (fig.2a), an independent built-in power source, a commutation and measurement system, and a numeric measurement indicator on the back of the mock-up. Measuring control is automatic. The device was used for measuring the EF E distribution over the body surface of the substation (SS) staff and linemen at work, and also for checking the screening effect of special clothes protecting humans from EF (fig. 2b). Table 1 gives a selection of E measurements taken on the surface of MEH-2 placed near the outdoor switchgear (OSG) of a 750 kV SS. MEH-2 measures the capacitive current flowing through the measuring electrode with a standardised surface area. The current value is later converted to E. The measurement results have shown that, if the value of E of a non-distorted EF at 1.8 m above the ground surface is equal to 17 kV/m, E on the MEH-2 surface changed from 2.8 kV/m (breast) to 243 kV/m (nose tip). Thus the measurement results show significant differences in the levels of distorted EF on the body surface and testify to possible local EF effects at the non-distorted field levels which are within standard values. These findings have been used in developing Sanitary Norms and Regulations of Occupational Exposure to Alternating EF of CF (50 Hz) (No 5802-91) in Russia, as well as in developing a uniform standardisation concept for both (electric and magnetic) components of CF EMF.

Table 1. Selection of E measurements on MEH-2 surface

Point No	E kV/m	Point No	E kV/m	Point No	E kV/m
1	143,9	15	243,1	32	149,6
5	92,1	18	15,0	51	16,0
8	67,8	24	56,0	68	7,2
11	115,2	25	2,8	75	43,2

3. **Calibration system.** To reduce measurement errors, **Grad-1** (USSR patent No 1366971) calibration system was designed and manufactured. It was used to calibrate measurement devices. A diagram of the calibration device is shown in Fig. 3.

Table 2 shows the calibration protocol for MEH-2.

Table 2
Calibration protocol for MEH-2 device

Measurement N	Calibration values		Indication	Error
-------	Current nA	E kV/m	Current nA	%
1	6,79	2,71	6,5	4,2
2	18,22	7,28	18,4	-0,9
3	27,57	11,01	27,6	-0,1
4	51,88	20,73	52,3	-0,8
5	135,97	54,33	140,4	-3,2
6	446,72	178,52	470,0	-5,2
7	904,17	361,34	942,0	-4,1

Maximum error of MEH-2 does not exceed 5.2%.

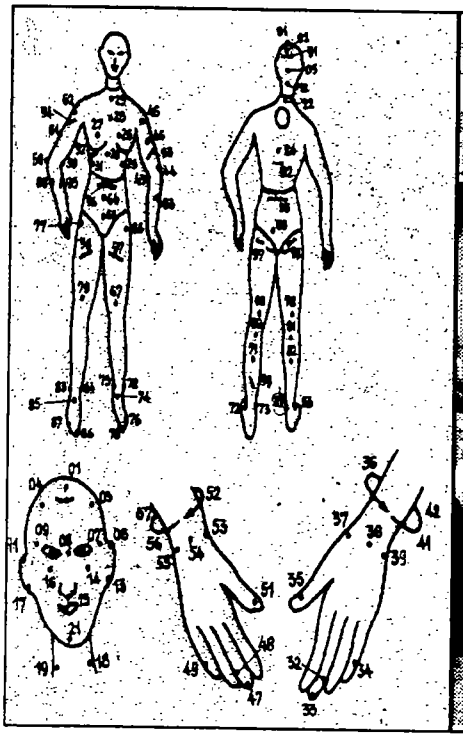

Fig.2a. Arrangement of electrodes on MEH-2 surface

Fig.2b. MEH-2 with a protective screening hat near the OSG of a 750 kV SS.

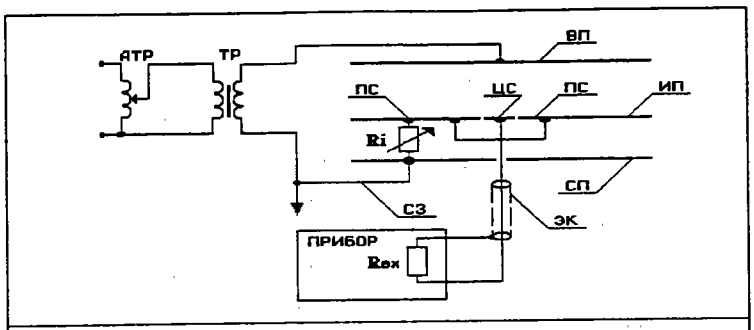

Fig. 3. Diagram of the Electric Field Strength Calibration System

4. **MEH-3 system** (see fig. 4) is also designed for measuring E values on the body surface. Is provided with 64 capacitive measuring sensors, built-in commutation and measurement systems, as well as with a computer input-output system controlling the measuring and processing its results. Was used for test-stand checks on the screening effect of protective clothes. It was found that the EF levels under the protective clothes were not in excess of the MPLs now in force in Russia, thus providing reliable protection for those at work.

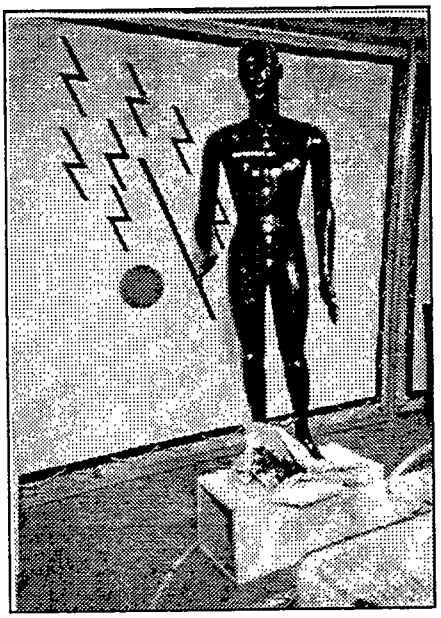

Fig. 4. MEH-3 device.

5. **MEH-4 system.** Designed to measure capacitive and air-ion currents in human body parts of those working on the maintenance of live overhead lines (OL) of super-high (SHV) and ultra-high (UHV) voltage. MEH-4 has 11 measuring zones (fig.5) and is provided with an independent power source (IPS), a commutation device (COM), a measuring unit (MU) and an input/output unit (I/OU) transmitting numeric information through the fibreglass communication lines (FGCL). FGCL are

used by the computer (which is at earth voltage level) to control the measurement process and to obtain measurement results. FGCL are not only communication lines but also an insulating link between MEH-4 which is at an OL SHV or UHV level and the computer which is at the earth voltage level. In each measurement zone 84 measurement per 0.02 s are taken with subsequent expansion to harmonical Fourier rank. The measurement results of air-ion (constant component of the current) and capacitive currents (first harmonic, i.e. 50 Hz) in the parts of human body of those engaged in 500 kV live TL maintenance without protective clothing are shown in table 3, while table 4 shows the same measurements taken when MEH-4 was in protective clothing (excluding shoes and gloves).

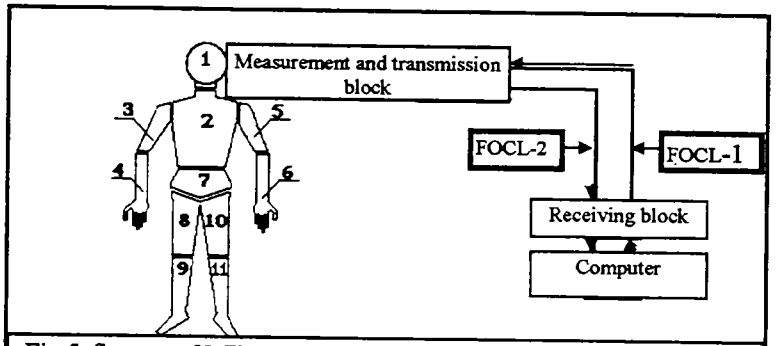

Fig.5. System of MEH-4 type
Measuring detectors arrangement.
Block diagram of measuring process.

Table 3.
Air-ion and capacitive currents in human body parts of those working near a live 500 kV TL without protective clothes.

Zone №	Current (constant component)	First Harmonic
1	-53,7	242,7
2	-88,2	197,5
3	14,5	98,7
4	167,3	494,3
5	21,5	65,1
6	-96,1	223,9
7	42,7	197,3
8	-156,1	185,7
9	121,2	949,2
10	21,2	159.2
11	-212,5	647,4

Table 4.
Air-ion and capacitive currents in human body parts of those working near a live 500 kV TL in protective clothes.

Zone №	Current (constant component)	First Harmonic
1	0,8	0,9
2	1,2	4,9
3	0,9	0,9
4	12,2	35,8
5	0,6	0,7
6	1,6	4,7
7	1,2	0,6
8	0,5	0,6
9	-0,3	4,6
10	0,7	0,5
11	4,0	46,9

Air-ion currents values are 15-84%, i.e. commensurate with amplitude values of CF capacitive currents. Screening clothes reduce air-ion current values from 16 (right shoulder) to 294 (thigh) times. CF capacitive currents show a still greater reduction: from 41 (trunk) to 313 (pelvis) times. The results support the assumption that in the live-line maintenance zone there are not only CF EF and MF but also capacitive (EC) and air-ion (AIC) currents too. They also demonstrate that the protective clothing is also highly effective in protecting those working in such zones both from EC and AIC, thus obviating the need for any additional hygienic regulations.

6. **MEH-5 system.** Designed to measure the strengths of CF EP in 64 points of human body surface of those working on the maintenance of live SHV and UHV OL (82 measurements per 0.02 s. **MEH-6 system** is designed to measure the amplitude-frequency spectrum of EF strengths generated by EMR associated with CD in 64 points of human body surface of those working on the maintenance of live SHV and UHV OL (4096 measurement per 0.005 s on each measuring electrode). Both systems are connected to a computer through FGCL. These systems are 50% complete (mock-ups with all coatings, measuring electrodes, cables, commutators and, in part, measuring devices) but the work on them has been stopped for lack of funds.

7. **Experimental setup and measuring system for EF strengths generated by direct current CD EMR on the surface of rat and mouse phantoms.** The experimental setup and measurment system are shown in fig.6 (NE - needle electrode, GE - grounded electrode, Rb – ballast resistor, SC - screening cable, HFA - high-frequency amplifier, ANT – alfanumeric transducer, CJD – conjunction device, P - printer). Fig.7 and 8 show the measurement results of volt-second characterictics of the mouse phantom voltage with +75 kV, and -75 kV on the needle-electrode respectively; fig. 9a and 9b show the design (according to the data in fig. 7 and 8 respectively) curves of the amplitude-frequency spectra (AFS) induced by CD EMR on the surface of the mouse body, the spectra obtained by recalculation to EP strengths with further decomposition to Fourier's integral by the Fourier rapid transformation (FRT) method. With positive polarity on the NE, the voltage splashes induced on the mouse phantom by

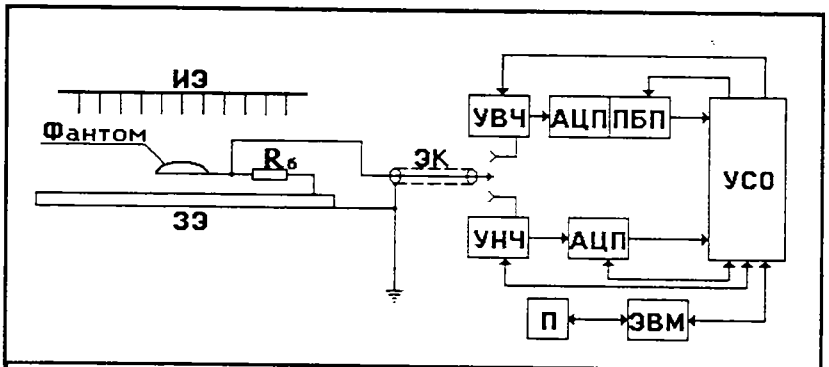

Fig.6. Corona discharge EMF measurement experimental setup and measurement scheme.

CD EMF, are very frequent, while the amplitudes are within a 200- 2000 mV range. With negative polarity, the splashes are relatively rare and the amplitudes are higher (500 - 1500 mV). With positive polarity, the shape of the strength AFS curve is complicated; the maximum values of E amplitudes are 10 to 50 V/m at the frequencies of 0.5 to 1.0 kHz. With negative polarity, the maximum values of E amplitudes are 50 to 200 V/m at the frequencies of 300 to 800 Hz. For both polarities the E amplitudes are damping at frequencies equal to or higher than 100 kHz. The data obtained show that the spectral characteristics of the wide-band lg(f) CD EMF spectrum parameters are similar to those at computer workstations, and

therefore require special attention to exclude their possible unfavourable effect on humans.

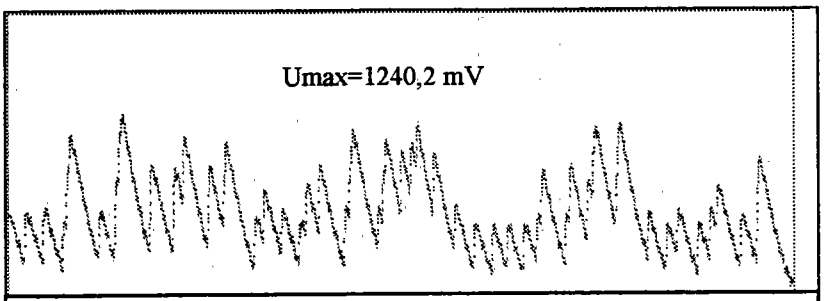

Fig.7. Volt-second characteristics of induced by direct current corona discharge EMF at mouse body phantom under + 75 kV voltage

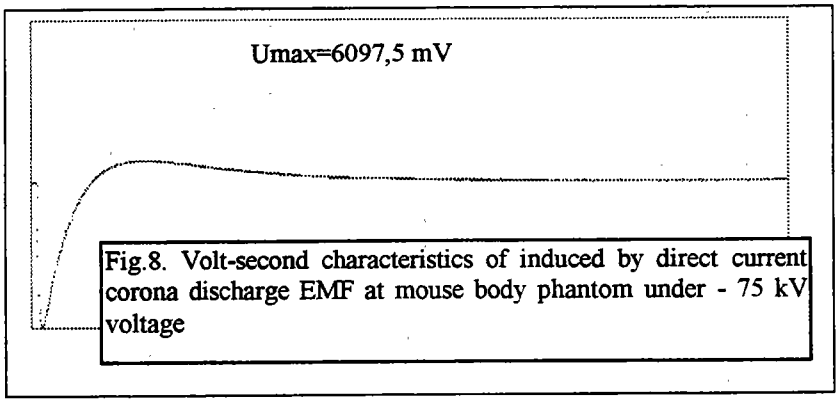

Fig.8. Volt-second characteristics of induced by direct current corona discharge EMF at mouse body phantom under - 75 kV voltage

8. **Razrad-1 system is designed for measuring E strengths, capacities and electostatic energy** induced on humans by friction of synthetic materials, contact with charged objects and exposure to TL DC air-ion currents (USSR patents Nos 1695582, 1711095). The system includes (fig. 10a) a discharging electrode, a capacitor unit (C_{10}-C_{12}), an amplifier (AMP), a conjunction device (CJD), and a calibration element (CE). The measurement is performed in two stages - first with the C_{12} capacitor disconnected, and second when it is connected. At every stage 84 E measurements per 0.02 s are taken on the C_{12} capacitor. The results are fed into a computer for processing. The change in the characteristics of the capacitor unit made it possible to considerably reduce the measurement

error bringing it down to at most 5%, while the 84 measurements at every stage enabled to single out a constant component of the E measured and to separate this measurement from the E of CF induced by household appliances, etc. Razrad-1 has been used in microelectronic industry for the verification of parameters of antistatic clothes designed for those working in hermetic zones (fig. 10b).

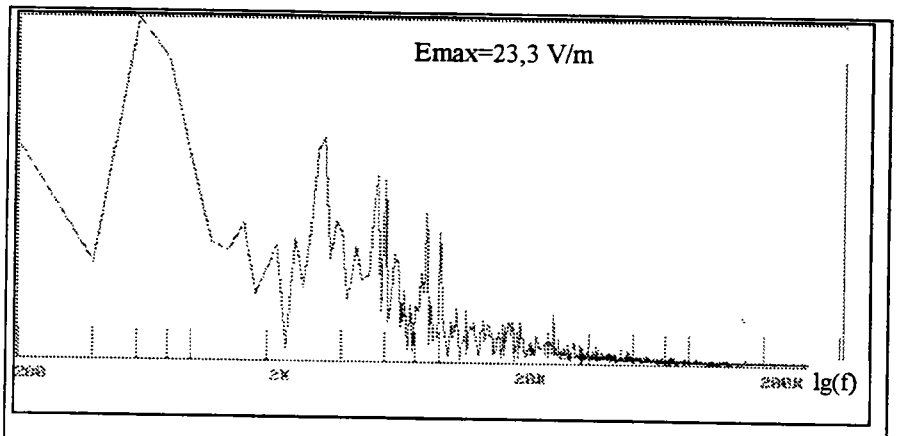

Fig.9a. Amplitude-frequency corona discharge EF strength spectrum at the mouse body phantom surface that induced by direct current corona discharge EMF under + 75 kV needle-electrode voltage.

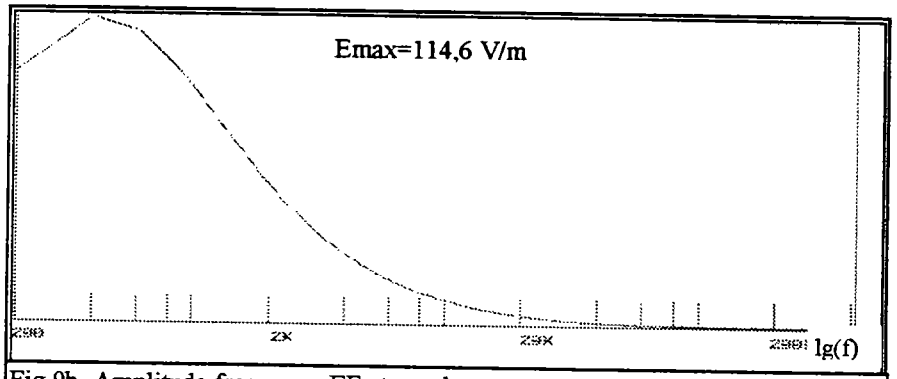

Fig.9b. Amplitude-frequency EF strength spectrum on the mouse phantom body surface induced by direct current CD EMF at + 75 kV on the NE.

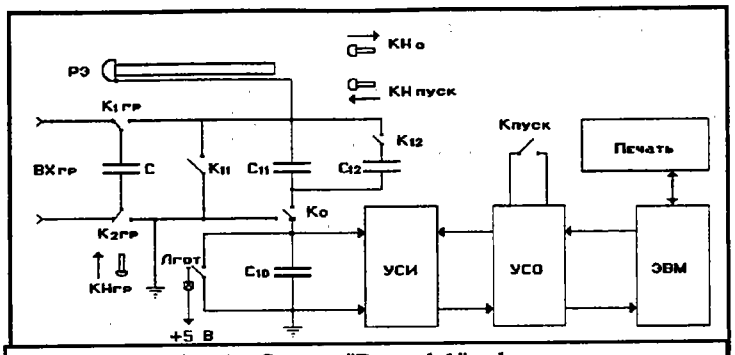

Fig.10a. System "Razrad-1" scheme.

Fig.10b. Testing the antistatic protective kit with Razrad-1 system for charge removal speed.

Electric and magnetic fields of SHV TLs.

1. **EF and MF strength distribution.** SHV TLs are the most active sources of EF and MF affecting humans, as they run over great stretches and may cross populated areas. To assess their impact on humans situated in the vicinity of HV lines special diagrams have been, and continue to be, made to show EF and MF strengths at the levels of 0.5, 1.5 and 1.8 m in the section of 110-1150 kV TLs. An example of resulting (without calculation tables) curves

of 500 kV TL E and H (greater elliptical semi-axis) values distribution at 1.8 m in a 500 kV TL section, depending on the distance from the lower wire to the earth, are shown in fig.11-14. These data allow to adequately evaluate eventual EF and MF values both at workplaces and in residential areas as early as the TL design stage and to change the design documents to exclude any unfavourable influence on humans. At present such evaluation forms an indispensable part of the standard regulations for CF EF and MF, in particular of the Sanitary Norms and Regulations of Works Performed under Exposure to Alternating EF of CF (50 Hz) (No 5802-91), and of the draft Sanitary Norms and Regulations of Occupatonal Exposure to Alternating EF of CF (50 Hz).

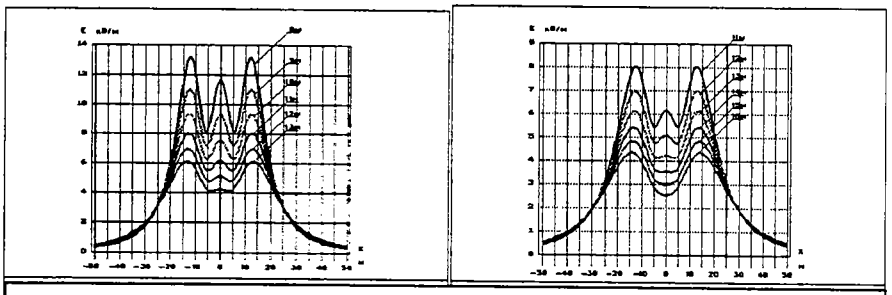

Fig. 11-12. 500 kV TL EF distribution at 1.8 m in TL section (depending on distance of the lower wire to the earth)

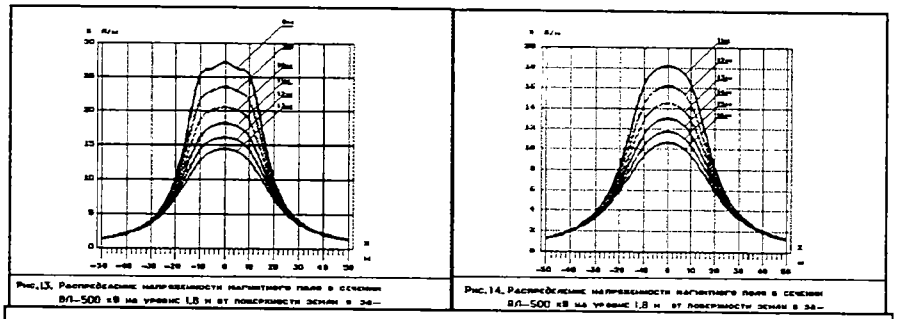

Fig. 13-14. 500 kV TL MF distribution at 1.8 m in TL section (depending on the distance of the lower wire to the earth)

2. **Step voltage under SHV TLs.** SHV and UHV transmission lines cross oil and gas pipelines, railways and highways where oil spills are possible. Taking an example of a conventionally built 750 kV TL passing over oil-

saturated soils it is shown that it leads to a non-uniform distribution of the induced voltage on the soil surface (fig.15). Step voltage can be as high as 1.2 kV, and this has to be considered while performing accident recovery works.

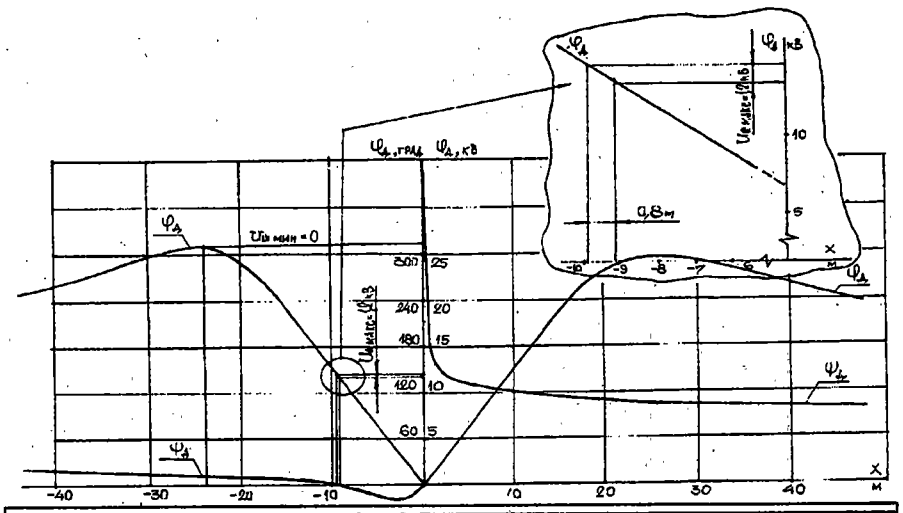

Fig. 15. Distribution of voltage at oil-saturated soil surface. Step voltage detection.

3. **Magnetic fields in SHV and UHV TL live-wire maintenance areas.** Screening clothes don't guarantee linemen's safety from intensive MF while performing live-line maintenance. To determine H levels in MF in order to single out the hazardous zones where H is in excess of MPL, calculations were made of H curves in the section of 220-1150 kV AC TLs and of 1500 kV DC TLs. Fig. 16 shows the distribution of H curves in 150 kV TL section, while fig. 17 – in 1500 kV section. These data were taken into account for the justification of MPLs while developing the Sanitary Norms and Regulations of Works Performed under Exposure to Alternating 50 Hz while Working with 220-1150 kV OL Live Wires (No 5060-89).

4. **Magnetic fields in the live-line maintenance zone during short-circuits.** Single-phase short-circuit (SC) operating conditions have been tested at the 750 kV TL substation of Vladimirskaya-Kalininskaya NPS. MF (fig. 18 and 19) on the surface of the damaged phase wires and lightning protection conductors at short circuit have values (22.8 kA/m for

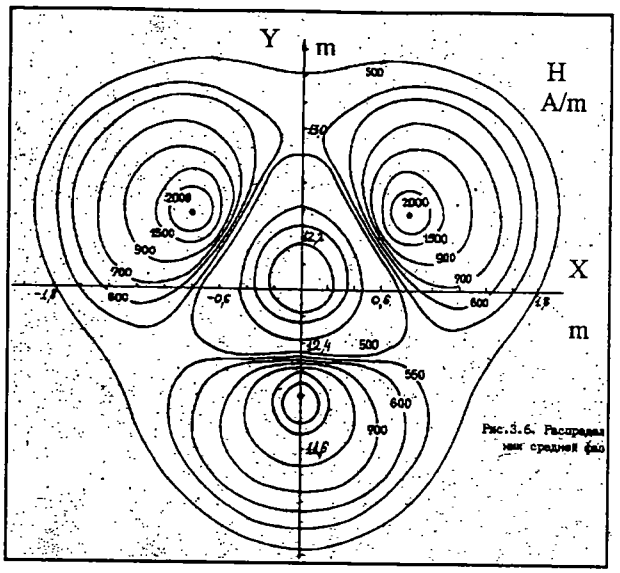

Fig.16. H level distribution in the middle phase section of 500 kV AC TL

the phase wire and 234 kA/m for the conductor) exceeding those established in Russia for safe H levels of general action MF (3.2 kA/m) over 7 times and those of local action (5.2 kA/m) 4.4 times. However, the duration of such an intensive MF is very short (0.06 s) which makes it impossible to compare these values with the standard ones, as the latter were established for continuous, and not for pulse, exposure.. The current density values j induced by MF from SC currents in human brain of those working on the live-line maintenance of 750 kV TL are 21 mA/m^2 for the phase wire, and 18 mA/m^2 for the conductor. These values are not dangerous for humans. The current curves in phase wires and conductors at the moment of single-phase automatic reclosing are not sinusoidal (fig.20 and 21), i.e. there are a rather quantity of higher harmonics. Induced in human brain by these currents MF under live-line maintenance current densities have complex form of time changing (fig. 22 and 23). The amplitudes are as high as 182 and 116 mA/m^2, respectively. With 1-10 mA/m^2

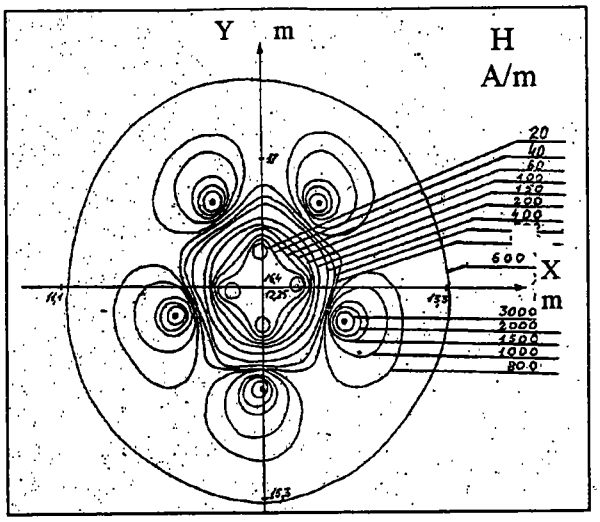

Fig.17. H level distribution in the pole section of 1500 kV DC TL

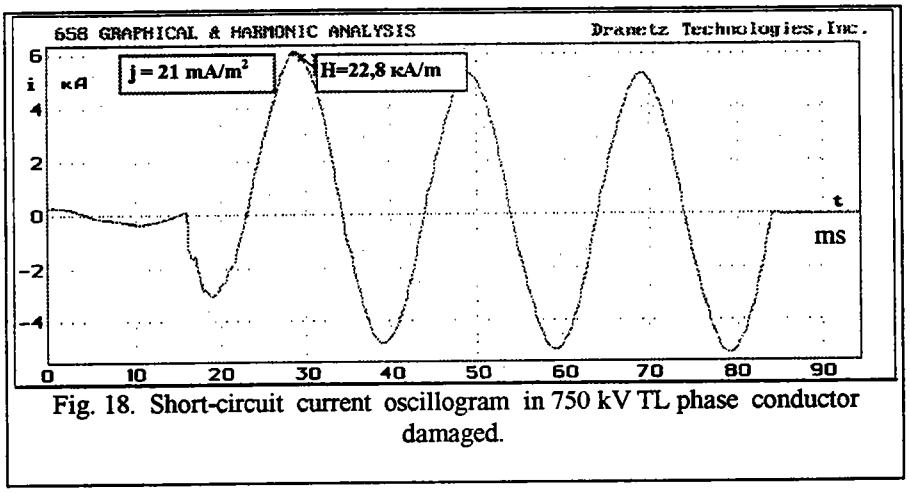

Fig. 18. Short-circuit current oscillogram in 750 kV TL phase conductor damaged.

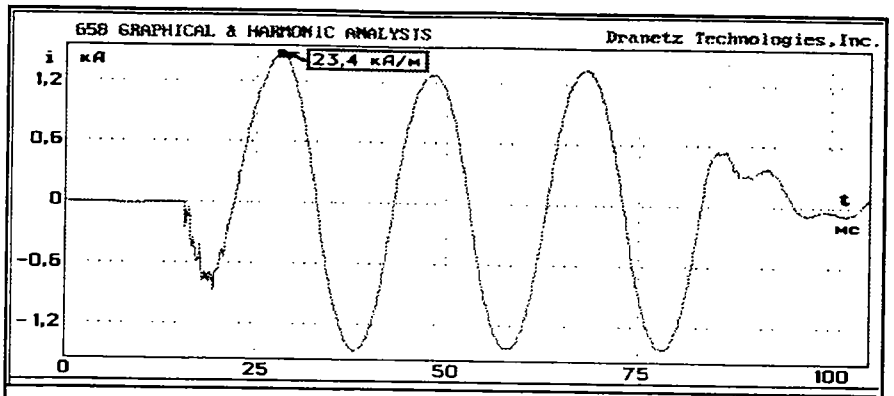

Fig.19. Short-circuit current oscillogram in 750 kV TL ground wire.

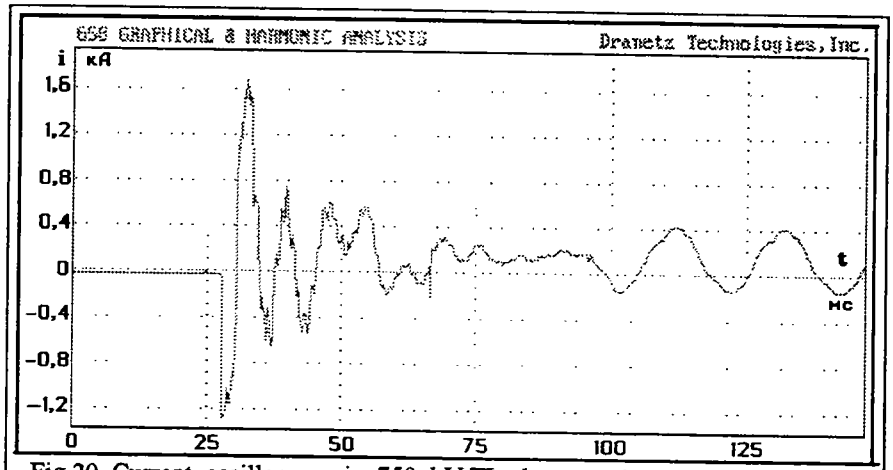

Fig.20. Current oscillogram in 750 kV TL phase conductor after automatic reclosing.

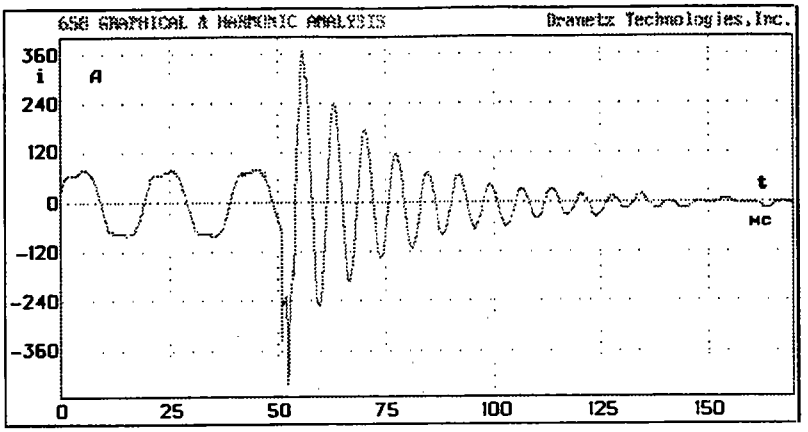

Fig.21. Current oscillogram in 750 kV TL ground wire after automatic reclosing.

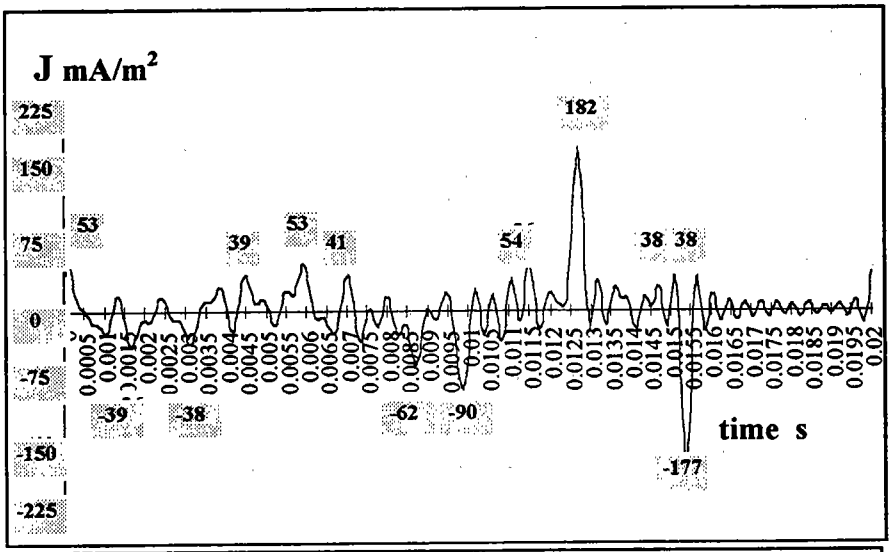

Fig. 22. Current densities in human brain values versus automatic reclosing phase conductor current

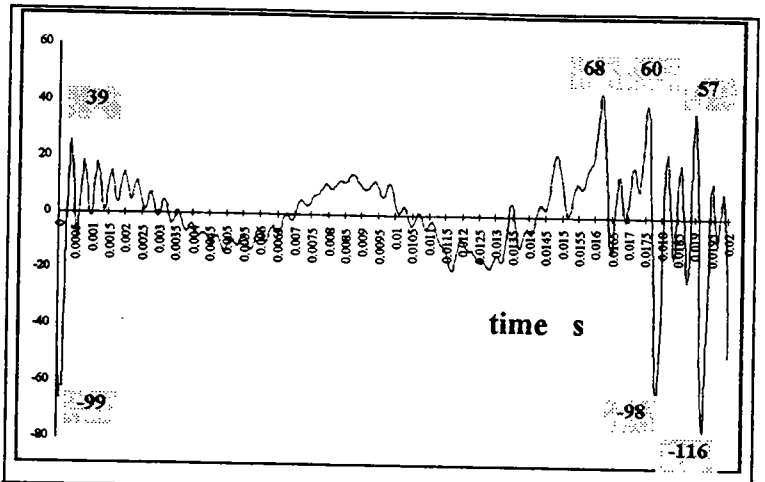

Fig. 23. Current densities in human brain values versus automatic reclosing ground wire conductor current

current densities, only minimal effects that are not hazardous for humans are registered; at 10-100 mA/m^2 marked visual and nervous system effects are provoked; 100-1000 mA/m^2 exposure leads to excitable structure stimulation and possible unfavourable health effects, while > 1000 mA/m^2 may provoke extrasystole and heart ventricles fibrillation (acute effects). Test results show that at SC j values are in the area of pronounced (perceptible) action, and in the area of excitable structures stimulation at the the moment of automatic reclosing. Short-circuit current values depend on the short-circuit loop resistance. Mosenergo Co 500 kV TL network maximum calculated short-circuit current values are 20-30 kA (acting values), hence H and j values may be 5-6 times higher. TL phase current values and shapes in at automatic reclosing are related to TL voltage and its other parameters (inductance, capacitance, resistance etc. - these may be different for different TL elements) as well as to switch arc parameters at reclosing. The inductance of 1150 kV TL is 1.5-1.8 times lower and capacitance 1.3-1.7 higher than those of 750 kV TL, therefore for this class of OL (and also for 750 kV OL) air-switches with still more sections of arc-gap zone are used. In that case the 1150 kV TL j amplitude values at automatic reclosing may be 2-3 times higher than for 750 kV TL. Then at 1150 kV TL short-circuit the j value passes into the perceptible action zone, and at automatic reclosing it comes close to the acute electromagnetic effect zone. Constant action of electromagnetic occupational factors under live-

line maintenance conditions, along with the heightened danger of working at great heights (which is a risk factor of its own), lead one to conclude that pulse MF induced currents in human brain, generated at successful automatic reclosing, may result in an increased health loss risk factor and present an additional danger to human health.

Ecologically safe SHV TL of elevated throughput capacity

SHV and UHV TLs are the main sources of environmental electromagnetic "contamination" as they are very long. Electromagnetic parameters management is possible by using compensating antennas (CA) that are either lightning conductors or wires or TL's second circuit phases (USSR patents No 931073, 931074, 1036222, 1050519, 1072731, 1382346). The CA method made it possible to create a mathematical model for arranging the double-circuit phases of TL to coaxial or single-radius couples. This solution enables one to minimize the radial E component and tangential H component outside the coaxial and single-radius couples, and therefore permits SHV TLs ecological safety as well as decrease its wave resistance. All this results in a 1.5 times increase of TL natural power (for one circuit). Fig. 24 shows the design of double-circuit single-radius 220 kV TL (DCSRTL) (800 MW power of it equal to that of a conventional 500 kV TL). That means that it can replace a conventional 500 kV TL in terms of throughput without causing electromagnetic pollution as seen from fig.25 and 26. A 330 kV DCSRTL equal to a conventional 750 kV TL - 2000 MW is shown in fig.27; while fig. 28 and 29 show respectively a 500 kV double-circuit coaxial TL (DCCTL) and DCSRTL power 5000 MW equal to a conventional 1150 kV TL. The maximum E level at 1.8 m under 330 kV DCSRTL, 500 kV DCCTL and 500 kV DCSRTL is lower than 1 kV/m; H levels are 2-4 A/m (DCSRTL) and 8 A/m (DCCTL), respectively. To decrease the wire heat losses one needs to increase the DCCTL and DCSRTL phase wire section, which results in increased costs. An economic comparison of different TL variants show that additional expenditures for 300 km 220 kV DCSRTL phase section increase are compensated by corona-discharge losses decrease and a lower power cost of substation equipment as well as by a 10% reduction in alienable land costs, and thus all the additional costs will be recovered over a 4 year period in comparison to a conventional 500 kV TL. Additional expenditures for a 330 kV TL in comparison with the conventional 750 kV TL expenditures are compensated within 6 years for the same reasons. 500 kV DCCTL and DCSRTL additional expenditures in comparison with a conventional 1150 kV TL are compensated just by a corona discharge decrease within 5 years. Thus the new TL designs may be not only ecologically safe but also economically advantageous.

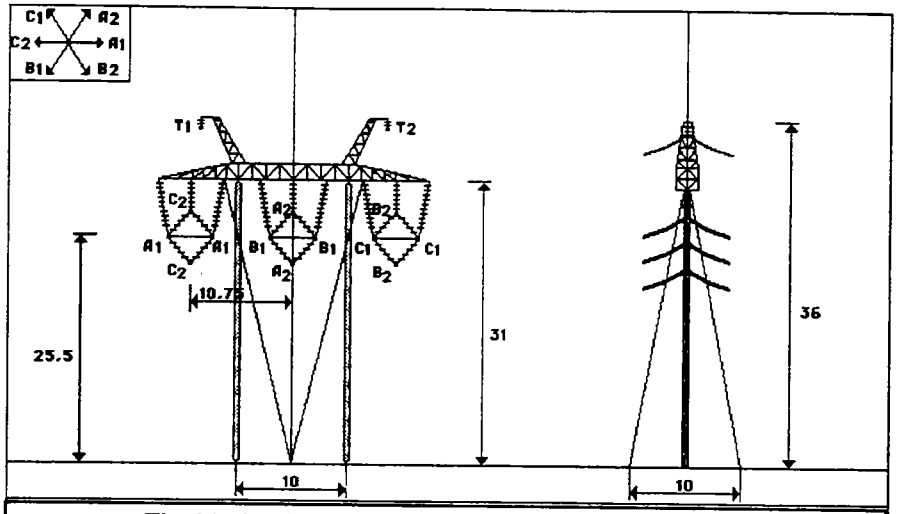

Fig. 24. 220 kV DCSRTL on reinforced concrete tower.

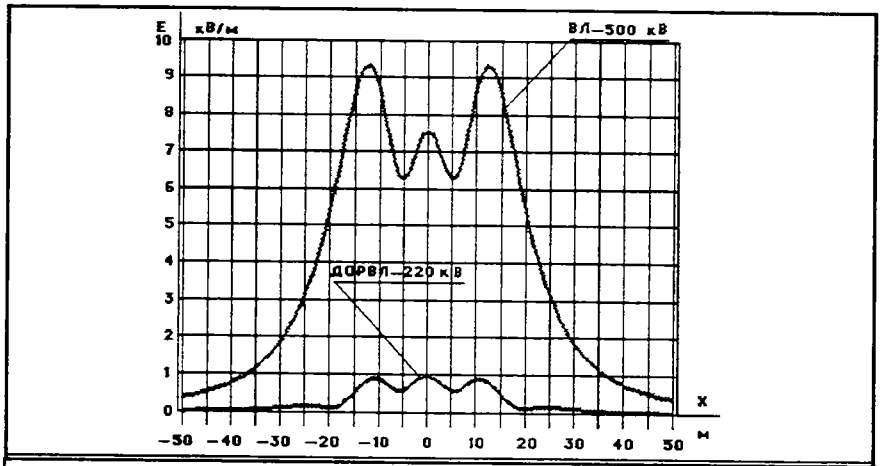

Fig.25. E level distribution under traditional 500 kV TL and 220 kV DCSRTL at 1.8 m high.

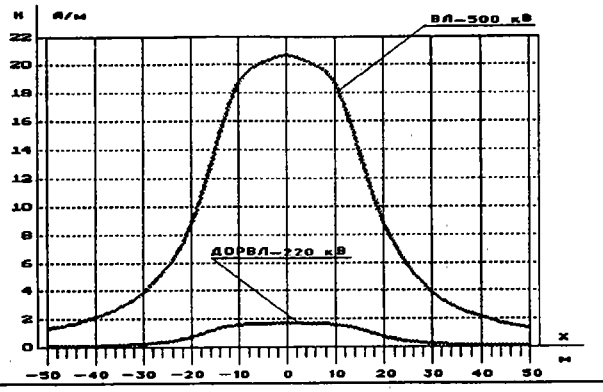

Fig.26. H level distribution under traditional 500 kV TL and 220 kV DCSRTL at 1.8 m high.

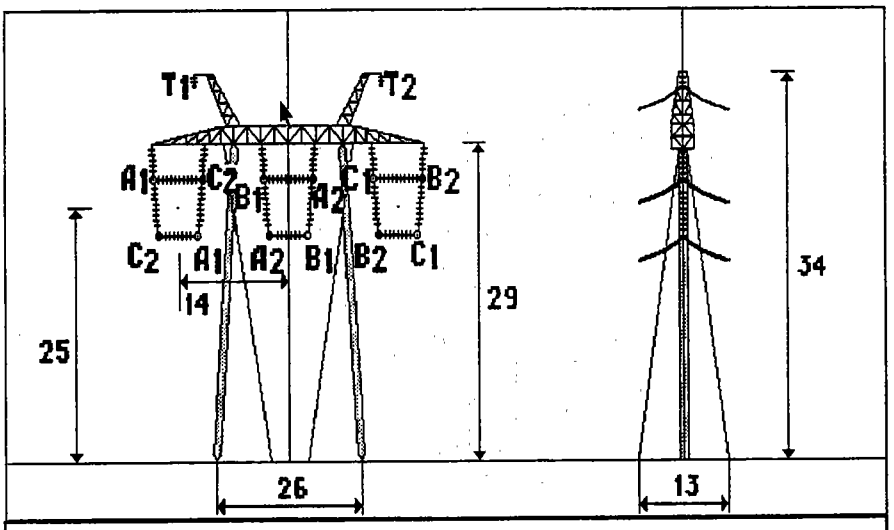

Fig. 27. 330 kV DCSRTL on reinforced concrete tower.

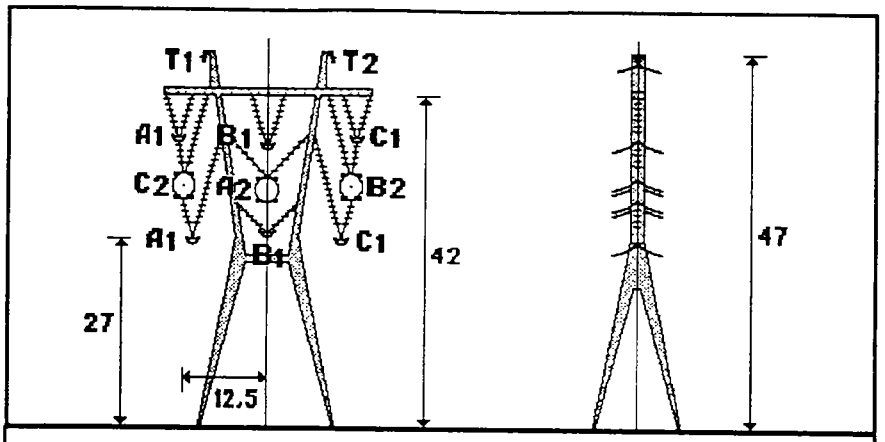

Fig.28. 500 kV DCSRTL on metal tower.

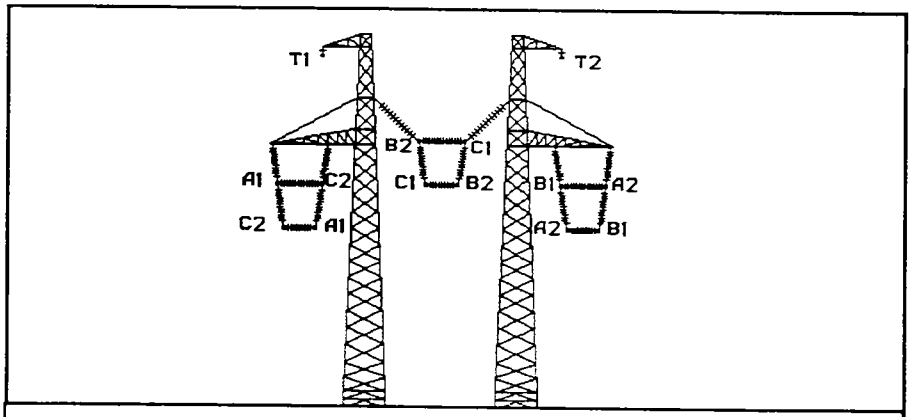

Fig. 29. 500 kV DCSRTL on PRS- type tower.

METHODS OF INSTRUMENTAL MONITORING OF ELECTROMAGNETIC RADIATION OF TECHNICAL FACILITIES AND TELECOMMUNICATION OBJECTS APPLIED FOR HYGIENIC EVALUATION OF THE FACTOR

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At present a lot of means of telecommunication, radiating electromagnetic energy, are located on the territory of Russia.

Being a biologically active factor an electromagnetic field may negatively influence humans and the environment.

A model called 'The system of human and environmental protection from the electromagnetic fields influence" and a generalised concept (applicable both in the urban zones and for the working places at radio industry companies) of providing the electromagnetic safety of telecommunication facilities have been worked out. It is based upon a comprehensive approach towards the solution of electromagnetic ecology issues. An electromagnetic monitoring sub-system is a part of this system and includes methods and means of electromagnetic radiation levels forecasting and measuring. Forecasting and measuring methods for telecommunication facilities are set forth in the approved Methods Directives [2-7].

Electromagnetic field features near technical facilities and telecommunication objects

Let us recall that an electromagnetic field is characterised by the electric field vector E, magnetic field vector H and the energy flow intensity vector (Umov-Pointing vector) P. In the free space ('wave zone') these three vectors are mutually perpendicular and their numerical values are definitively related as follows:

$$H = E/120\pi; \qquad P = EH \tag{1}$$

The field formed near radio frequency telecommunication facilities is the so-called 'closer field' or Fresnel field (the distance from the radiating objects is defined by the condition $r < R2/l$ where R is the maximum dimension of the

radiating system and l is the wavelength). This field is not a plane wave field and above-quoted ratios are not true in this case.

In a closed space (e.g. generating equipment rooms) and near metallic (re-radiating) a complicated interfering picture of the field distribution is established when the radiating means in operation. Different slits (in the transmitter screens, feeder flange connections, outlets from the buildings where closed feeders change into open ones, etc.) account for the formation of magnetic dipoles established on the opposite side of the screen by the energy flow falling on it. In this case at distances exceeding the wavelength the field intensity behind the screen may be rather low. However, with the distance decrease the field intensity will be increasing, approaching at very small distances the intensity of the field on the opposite side of the screen. In this case a longitudinal component of the field strength is established near the radiation sources, a phase shift appears between the resultant components of the electrical and magnetic fields and the change of the absolute value of the field strength greatly increases compared to the changes in the 'wave zone', through the increase influence (different for electrical and magnetic fields) of the 'quasi-permanent' components changing as $1/r^2$ and $1/r^3$.

Closely located metallic surfaces influence the qualitative and quantitative changes of the original field, softening the picture of the spatial field distribution through the disappearance of deep shadows and the appearance of the noticeable qualitative field non-uniformity because of the reactive character of the field of the re-radiating elements and establishment of clearly pronounced stationary waves in closed space.

Because of the lowered (compared with the open space) characteristic impedance of the environment in the induction field the amount of power absorbed by the organic material increases. On the other hand, the specific increase of power of the magnetic component of the field is observed near the loose fittings in the screens. As a result the complicated field structure formed by radiation facilities both at the working places of the personnel and in the urban territories imposes certain conditions on the methods of measuring the electromagnetic radiation levels.

General requirements concerning measuring instruments at electromagnetic radiation levels hygienic evaluation

Instruments designed for electromagnetic situation monitoring with the aim of ensuring human safety must make it possible to measure those electromagnetic

radiation levels parameters and values which are set forth in the process of standardisation and calculated forecasting.

All methods of designing instruments for field strength measuring are based on using receiving antennas (sensors, sounders) at whose output e.m.f. is induced proportionally to the electric field strength for dipoles and to the magnetic field strength for loop antennas, and also broadband or selective detectors.

Antenna is a major component of the field measuring device. Recently either 'pure' dipole or loop antennas [8-11,16] or their combinations (isotropic antennas, tripoles) [8,12-15] have been used for this purpose. The output voltage of these antennas is proportional to the field strength vector absolute value, i.e. root-mean-square value. Further transformation is carried out according to one of the methods described in [17] using modern electronic circuitry. In this case the lack of disturbance of the measured field is one of the main requirements for the dimensions of all types of antennas. The requirement is met when the antenna dimensions are much smaller than the radiation wavelength, with signals transmitted to the detector over either high-resistance transmission lines or fibre-optical transmission lines to reduce the disturbance of the measured field.

Considering the fact that from the ecological point of view the energy characteristics of the field in different frequency bands have different standard values, the evaluation of electromagnetic situation formed by the resultant field, which is measured with broadband detector instruments, is becoming an issue not likely to be solved without taking certain organisational and technical decisions.

Consequently, the evaluation of the electromagnetic situation, created by a complex system of the fields with different frequencies, is advantageously carried out with the systems based upon selective detectors (voltmeters and measuring receivers) and suitable measuring antennas.

An instrument, representing a means to measure the energy characteristics of electromagnetic radiation sources, must meet a series of requirements providing the possibility of its application for measuring purposes. These requirements include:

- frequency range;
- dynamic range of the measured electromagnetic radiation levels;
- width of received signals band and selectivity;

- efficient screen against outer electromagnetic radiation;
- measuring antenna type;
- measurement accuracy.

The above-mentioned parameters must be unchanged when measuring the electromagnetic radiation levels both at the working places and in the urban territory and reflect the equipment structural features and the field structure in a zone where radiation sources are located.

Dipoles, frames and aperture antennas are used as measuring antennas. However, specific requirements are set for the measuring antennas, including dimensions, ability to measure both magnetic and electric components in the point of measurement if field strength is measured in a closed space and near re-radiating constructions (which is characteristic of the service personnel workplaces).

Accuracy of the inner fields measurements in a closed space is influenced by:

- measuring antenna dimensions since the outer field near re-radiating surfaces is highly non-uniformly distributed in space;
- mismatch of the structures of the field for which the antenna is designed and the reactive field of radiating slits and re-radiating objects both near and far from them in the stationary wave field formed in the closed space;
- strong mutual influence of antennas when measuring at distances comparable with the wavelength and radiating objects dimensions. Electromagnetic field level evaluation in close proximity to re-radiating constructions in a closed space can be carried out only if all the above-mentioned requirements determining the measurement accuracy are met.

Thus the following requirements are set for the measuring antennas:

1. eliminating the mutual influence of the measuring antenna and radiating objects;
2. ability to measure both electric and magnetic field strengths;

3. measuring of the three mutually orthogonal components of the electromagnetic field strength.

The list of devices recommended for the hygienic evaluation of electromagnetic radiation in different frequency bands and corresponding measuring methods are described in [2-7].

Organization of activities on instrumental electromagnetic radiation monitoring

To monitor the electromagnetic radiation of technical equipment and telecommunication objects it is necessary to take some organisational and technical steps.

Organisational steps:

- to prepare and study the necessary standards and specifications setting maximum permissible levels of radiation with electromagnetic fields for human beings, methods of calculated forecast and full-scale radiation levels measuring, regulations for development, co-ordination and approval of a technical means and/or whole object sanitary certificate;
- to prepare all the necessary documents on the parameters of the technical equipment of the object to accomplish a calculated forecast;
- to prepare a layout of the object location and the nearby territory with the existing buildings and plans for its future development;
- to make up a task list for accomplishing the calculated forecast of the electromagnetic situation;
- to prepare and study the necessary measuring equipment;
- to define a group of experts directly involved in the electromagnetic situation monitoring.

Technical steps at full-scale measuring:

- to organise operation of all technical equipment, included into the calculated forecast, according to the wave schedule;

- to ensure that the equipment parameters used for the forecast and the measured parameters match each other;

- to plan and carry out prior examination of the territories for measurements.

Features of electromagnetic radiation levels measuring method for facilities and objects of low, medium and high frequency bands

It is common knowledge that a modern radio-broadcasting centre uses telecommunication facilities operating at different frequencies both in the same and in different frequency bands. The electromagnetic field structure near low, medium and high frequency bands antennas is extremely complicated and depends upon many factors: antenna types, working frequencies, radiated power level, radiated field polarisation, electrophysical features of the soil, topography, plants, types and quantity of buildings, antennas' mutual influence.

A specific feature of forecasting and measurement of electromagnetic radiation levels in low, medium and high frequency bands is the necessity to estimate the field at distances comparable with the antennas' geometrical dimensions and wavelength.

In this case the antennas, establishing the fields of mainly one type of polarisation (vertical or horizontal) in the wave zone, create fields of other types of polarisation in the closer zone with their levels comparable and sometimes exceeding the levels of the basic polarisation.

Electrical (magnetic) field strengths in any space point around antennas, radiating a horizontally polarised field to the 'wave zone' and located above earth surface with real electophysical parameters, have three components E_x, E_y and E_z (H_x, H_y and H_z) in the Cartesian co-ordinate system and are defined as follows:

$$E = (E_x^2+E_y^2+E_z^2)^{1/2} \quad \{H = (H_x^2+H_y^2+H_z^2)^{1/2}\}$$

Electrical (magnetic) field strengths in any space point around antennas, radiating vertically polarised field to the 'wave zone' and located above earth surface with real electophysical parameters, have two components E_r and E_z in the cylindrical co-ordinate system and are defined as follows:

$$E = (E_r^2+E_z^2)^{1/2},$$

while magnetic field strengths have one component H_φ.

Consequently, instrumental monitoring of electromagnetic radiation of telecommunication means and objects of low, medium and high frequency bands requires measuring of all components of electrical and magnetic fields (electromagnetic field vector) established by each technical facility. The resultant electromagnetic situation evaluation is carried out according to the formulas given in /1/.

Features of electromagnetic radiation levels measuring method for facilities and objects of the very high frequency band

The very high frequency band lies within 30-300 MHz. Television and FM radio transmitters operate within this band. A specific feature of standardising the electromagnetic radiation strength of a field established by these technical means is the frequency dependence of radiation maximum permissible levels [1]. Naturally, this imposes special requirements on the measuring equipment.

It should be noted that transmitting antennas of very high frequencies FM and TV broadcasting are located on rather high masts (supports). That is why we can consider that a random observation point near the earth surface is located in the antenna distant zone where the field front is established and directivity features do not depend upon the distance. Very high frequencies FM and TV broadcasting antennas are dipoles and establish linear polarised fields in the 'wave zone', i.e. fields of vertical or horizontal polarisation.

In the distant zone of radiation the electrical and magnetic components of electromagnetic radiation are related according to (1). Thus it is sufficient to measure the electrical field strength while the magnetic field strength is calculated according to formula (1).

A specific feature of applying the method in the urban territory is measuring an electric field of corresponding polarisation at each working frequency (for TV broadcasting - at working frequencies of the video and audio channels) with selective detectors. Within the buildings and at the personnel working places we measure all the electrical field vector components (as in low, medium and high frequencies bands) at each working frequency.

Features of electromagnetic radiation levels measuring method for facilities and objects of ultrahigh, super high and extremely high frequency bands

A specific feature of ultrahigh, super high and extremely high frequency bands is that maximum permissible levels of electromagnetic radiation for them are standardized by the energy flow density.

Different types of transmitters operate within these bands, including TV broadcasting centers, mobile communication facilities, direct visibility and tropospheric scattering relay stations, satellite communication and broadcasting facilities.

Methods of electromagnetic radiation levels measuring in ultrahigh frequency band can be divided into two groups: field strength measurement and energy flow density measurement.

Methods of field strength measurement are identical to those applied for the very high frequency band and are used for hygiene control of electromagnetic radiation of the TV broadcasting centers and mobile communication central stations in the urban territories. Further calculation of the value of the field strength electrical component in the energy flow density is carried out according to formulas (1).

Energy flow density measuring methods are given in [7].

The results of the instrumental monitoring of the electromagnetic situation within the territory of location of a number of radiating facilities and telecommunication means, carried out in accordance of the above mentioned specific features, showed a high rate of agreement with the forecast.

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RESULTS OF METROLOGICAL INVESTIGATIONS OF MEASURING INSTRUMENTS OF ELECTRICAL FIELDS EXCITED BY VIDEO DISPLAY TERMINALS

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With the approval, in 1994, 1996, of State standards of units of the electric field strength GET 45-94, GET 158-96 and introduction of GOST 8.560-94, GOST R 8.564-96 for measurements chains, transition was effected to a centralised method of reproduction of the unit of the electric field strength V/m and there arose an opportunity of unification of methods and means of verification of the working standards and measuring instruments. In this connection the experts of GP VNIIFTRI conducted metrological investigations of 10 of types of devices, used in Russia for measurement of strength of electrostatic and alternate electrical fields, excited by video display terminals. The results obtained for metering devices of strength of an alternate electrical field are indicated in table 1, and for those of strength of an electrostatic field - in table 2.

Frequency band 1 is from 5 Hz up to 2 kHz; frequency band 2 is from 2 up to 400 kHz; δE_{pass} – admissible error limit of the investigated device according to its certificate; δE_{act} - actual error of measurement of a reference electric field strength.

It follows from the above-mentioned tables, that four out of the six of meters of alternate electric field strengths have an actual error of measurement several times exceeding the error, indicated in the normative documentation. Similar results have been obtained for meters of the electrostatic field strength. Only one of the four types of measurement devices displayed errors within the range indicated in its certificate. The data obtained were confirmed by comparison of the results of measurements of the strength of alternate electric field, excited by the same monitor. So, for example, the difference of the indications of the American (H I-3638) and Swedish devices (EMM-4) is as great as 3 times.

These results point to an infringement of traceability in low-frequency area of measurements of electric field strength.

One of the reasons of this situation was the absence of a normative document, regulating technical requirements and methods of tests of meters of strength of an electrical field. It was found that the tests of measuring instruments

and primary verification (calibration) were conducted in conditions, which greatly differed from those of their practical application. As a result, it was not noticed, that the devices of EMM-4, " Screen scanner 1 ", "IEP-04", "EMF-57", "IEZ-P", "IESP-5C" types react not only to strength of an electrical field, but also to its potential. As the relation of these quantities depends on the kind of the source and on the point in space, the error of measurement of strength of an electrical field becomes an uncertain value.

Table 1
Measurement devices for electromagnetic radiation of video display terminals

##	Name and type of the device	Manufacturer	Frequency band	δE_{pass}, %	δE_{act}, %
1	Meter of electromagnetic radiation of video display terminals PZ 28	SKB RIAP, Russia	1 2	±20 ±20	12 9
2	ELF/VLF Electric Field Meter HI-3638	Holiday Industries, USA	1 2	±13 ±13	12 6
3	Instrument for the measurement of alternating electric fields EMM-4	Raians Innova AB, Sweden	1 2	±6,6 ±7,4	150 150
4	Complete set of indicators of levels of electromagnetic radiation of means of display of information and computer facilities Screen scanner 1	AO Russian Shield, Russia	1 2	±30 ±30	220 200
5	Tester of means of display of information IEP-04	NPP Cyclone–Test, Russia	1 2	- ±14	190
6	Meter of electrical and magnetic fields B&E-meter	AO MTM-ZASCHITA, Russia	1 2	±15 ±15	80 -

Table 2
Devices for VDT strength of an electrostatic field measurement

##	Name and type device	Manufacturer	δE_{pass}, %	δE_{act}, %
1	Meter of strength of an electrostatic field Ì3-27	SKB RIAP, Russia	±15	-10
2	Influence Electric Fieldmeter EMF 57	Eltex, Germany	±15	525
3	Meter of electrostatic charges a portable IEZ-P	Z-d Microwire, Moldova	±25	100
4	Meter of strength of an electrostatic field IESP-5C	NPC EMC, Russia	±10	200

The infringement of a traceability was to a considerable degree caused by the introduction of the GOST R 50949-96 standard, which, besides the methods of measurements, contains requirements as to the design and methods of calibration of measuring instruments of electrical fields, as well as an appendix with recommendations, which contains devices, which includes the devices that have not passed the tests in accordance with the requirements of PR 50.2.009-94. All this is a direct consequence of the aspiration of co-ordinating, by any means and as soon as possible, Russian standards with the European ones. Such an aspiration does not cause any objections in itself, if, first of all, only time-proven standards accepted in many European countries are taken as a basis, and secondly, if they harmoniously fit into the Russian system of the standards and metrological practice currently in force.

In our opinion, the factor, stabilising a situation, is the introduction of GOST R 51071-97 " Meters of strength of electrical and magnetic fields. General technical requirements and methods of tests ", which permits to make uniform the procedure of tests of new devices and to restore traceability in future. Besides, with the introduction of compulsory certification of video display terminals and PC operators' workstations, the NTK of Gosstandart of Russia has decided to take a number of immediate measures: to introduce changes to the sections of GOST R 50949-94, concerning requirements on meters of strength of electrical fields; to inform organisations, conducting verification and calibration of the working standards and of measuring instruments, about the infringement of traceability while conducting the measurements of strength of electrical fields and about the necessity to observe the requirements of the standards GOST 8.560-94 and GOST R 8.564-96 on the measurements chains of means of measurement of electrical field strengths.

Session 3: GENERAL RESPONSE TO EMF EXPOSURE

NONSPECIFIC INITIAL ADAPTIVE REACTION OF THE BRAIN TO VARIOUS ELECTROMAGNETIC FIELDS

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The scientific-technical revolution of our day is associated with the wide introduction of various electromagnetic fields /EMF/ in almost every aspect of life, in industry, in medicine and everyday life. Policy recommendations are suggested for electromagnetic pollution prevention and control in Russia in the context of recent developments and WHO guidelines, as well as the international perspective (Demin, 1997).

It should be noted, that the EMF from static (SMF) and alternating (AMF) magnetic and electric fields, and up to the light range involve non-ionising radiation and are a significant factor in the natural and anthropogenic environment. Theoretical studies of their biological action help in solving the practical problems of ecology, hygiene, therapy and diagnostics. However, from our point of view, application of artificial EMFs as stimulators in neurophysiological laboratories opens up new prospects for the solution of theoretical problems, connected with the study of the perception mechanisms of conscious and unconscious stimuli (Kholodov, 1966, 1994, 1998).

At the beginning of the century there already was an indication that the nervous system /NS/ played an important role in body reactions to EMF. At present the experimental models in vitro predominate over models in vivo (Adey, 1990).

The goal of this report is to present some results of investigation in the laboratory of electromagnetic neurophysiology. We used four methods: psychophysical, electrophysiological, morphological and behavioural, - and also four EMFs: microwaves /mm- and cm-ranges/, pulse magnetic field /PMF/, CMF and AMF/ and magnetic shielding room /MSR/. In Table 1 we can see the forms of EMF, its intensity, frequency, duration and the device used.

The first type of initial reaction of NS to EMF was discovered when we used the psychophysical or electrophysiological method during local stimulation /hand or head/ of any EMF /see table 1/. In comparison with the human initial sensory reactions to usual stimuli /light, sound/ or to AMF exposure of head

/magnetophosphen/, the reactions to EMF exposure of skin were distinguished by a long /about 30 s/ latent period.

Table 1
Characteristics of using electromagnetic fields

Electromagnetic field	Intensity	Frequency	Device	Duration
Microwaves mm-waves	5mW/cm^2	42,25 GHz	«Jav-1»	1-30 min
cm-waves	2-200mW/cm^2	3 GHz	«Luch-58»	1-60 min
Pulsing magnetic field	0,3-1,0 T	20/min	«AVIMP»	1-30 min
Magnetic field AC	3-300 mT	50 Hz	«Magniter»	1-60 min
DC	0,2-200 mT	-	Coil	1-60 min
Magnetic shielding room	5.10^{-8}-5.10^{-7}T	-	Screen	1-60 min

A volunteer was placed in a dark sound-proof chamber and was instructed, after hearing a click, to respond to any sensation felt by pressing the button which switched off the source of EMF and switched on the EEG recorder. The electromagnetic stimuli and false signals were presented randomly with intervals of 1-3 min. In the verbal report after each test the subject indicated the modality of the sensations, their localisation and duration. The results were evaluated by the methods of mathematical statistics.

An analysis of the sensory signals has shown either a lack of sensations, or weak pain /55%/, pressure /25%/, touch /15%/, warmth or cold /5%/. These results gave rise to the idea of the participation of the nociceptive system in reactions of the body to various EMF.

This conclusion was confirmed by the experiments with chlorethyl anaesthesia of the skin part which was exposed to EMF. In Fig.1 it is seen that with a stable dynamics of the true reactions to AMF of volunteer N. /about 90%/ and false alarms /about 50%/. In the course of 10 experiments this picture did not change. Under the influence of chlorethyl the stability of true reactions reversibly lowered to the level of false alarms, but not to zero. It follows that false alarms are generated by CNS and are not influenced by chlorethyl.

Fig.1. Dynamics of stability of sensory reactions to AC MF (40 mT, 50 Hz)
Volunteer N. during chlorethyl anaesthesia of hand.
1 - true reactions,
2 - false reactions.
Arrows indicate the period of anaesthesia.
Ordinate - stability in %.
Abscissa - numbers of tests.

In more detail, sensory responses to EMFs are described in our book /Kholodov, Lebedeva, 1992/ and confirmed by other investigators /Stefanov and Statev, 1988/.

Human EEG registration is a more objective method than sensory indication. While recording EEG during a subject's exposure to EMF we could see slow rhythms /alpha and theta/ predominate mostly in the frontal area of the right hemisphere.

Electrical activity of various cortical and subcortical structures of the brain was investigated in unanaesthetised animals prior, during and after EMF exposure /SMF, AMF, PMF or MW/.

25 rabbits were used in the experiments with SMF. An animal was gently restrained in a wooden frame and its head was exposed to a 40-100 mT SMF. The most frequent and reliable result of the exposure was an increase in the number of spindles, slow waves and sometimes sharp waves.

Figure 2 gives the results of counting the number of changes, i.e. the number of spindles and slow waves, for every 10 seconds of EEG recording. This graph includes the results of 100 exposures to 100 mT SMF or to sound and 100 control recordings of EEG of the same rabbits. The last data were taken as 100%.

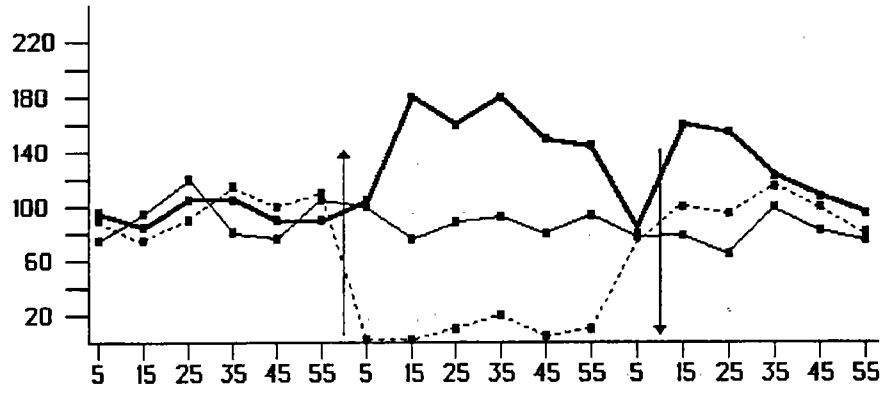

Fig.2. Dynamics of EEG changes of rabbits to DC MF 100 mT (thick line), to sound (interrupted line) and in controls (thin line).
Ordinate - number of changes in %.
Abscissa - time in seconds.

The control experiments showed no reliable EEG changes, the sound decreased these changes to zero during the entire time of stimulation. A significant rise in the curve did not begin until the 15th second of SMF exposure (long latent period!). It is interesting that 15-25 seconds after the electromagnet is turned off, there is a statistically reliable ($p < 0{,}001$) increase in the number of spindles and slow waves, which almost approximates the basic reaction in intensity, but lags behind it in duration. This off-reaction sometimes occurs in the absence of the basic reaction.

In more detail, EEG synchronisation reaction to various EMFs was described in our book /Kholodov, 1966/ and was confirmed by other investigators /Chizhenkova and Safroshkina, 1966/.

The EMF simultaneously produced changes in the electrical activity of different brain structures. There was a definite hierarchy of the intensity of the reaction.

Normally the most intensive reaction to SMF was observed in the hypothalamus, then came the sensomotor cortex, the parietal cortex, the specific nuclei of the thalamus, the non-specific nuclei of the thalamus, the hippocampus and the reticular formation of the midbrain. After the injection of caffeine the intensity of the reaction to SMF increased in all sections of the brain, but it was in the sensomotor cortex where it most sharply increased. After the injection of adrenaline the first place was taken by the reticular formation of the midbrain. Thus, the SMF acts on each section of the brain, but the intensity of the reaction is determined by reactance of its separate sections.

By artificially increasing the excitability by means of pharmacological, mechanical or radiation agents we can change the form of EEG synchronisation reaction. One can see not only an increase in the number of spindles, slow and sharp waves, but also observe epileptic discharges.

Our experiments on monkeys have shown that PMF at the intensity of 0,3 T can provoke epileptic discharges in EEG and cause convulsive muscle contraction. Although these monkeys were sensitised to epileptic fits by previous implanting of deep electrodes in the brain or by exposure to ionising irradiation, a similar state can occur in the patients treated with brain magnetic stimulation.

AMF intensities of about 30 mT can increase the number of epileptic discharges in EEG of rats of special breed Wag/Rij, which is a model of petit mal. It is known that slow waves and epileptic discharges in EEG are connected with activity of neurones and neuroglia.

The reaction of neuroglia and neurones was determined by morphological methods together with Prof. M.M. Aleksandrovskaya, Prof. L.M.Merkulova, N.I.Artjukhina and others. The examination was conducted dynamically after the animals /rabbit, cat, rat/ were placed in a 100 mT SMF for 3 minutes, 1, 10 or 60 hours. The animals were slaughtered immediately after the exposure. An analysis of the histological of the sensomotor cortex of the controls and experimental animals has shown the following.

Figure 3 indicates that in the control experiments $9,0 \pm 0,5$ astrocytes were detected. After 3 minutes of MF exposure their number was $16,7 \pm 0,4$. The neurones remained intact.

1 hour after the start of the SMF exposure, we noted a sharp productive reaction of the astroglia (23±0,5). The neurones remained intact.

10 hours after the start of the MF exposure the reaction of the glia remained productive, including the perivascular and marginal glial fibrosis. The neurones underwent reversible changes in the form of swelling and hyperchromatosis.

60 hours after the start of the MF exposure we observed a picture of hypoxic encephalopathy with dystrophic changes of the glia.

In more detail, the morphological reactions of the animals' brain was described in our book /Merkulova, Kholodov, 1996/ and was confirmed by other investigators /Artjukhina, 1989/.

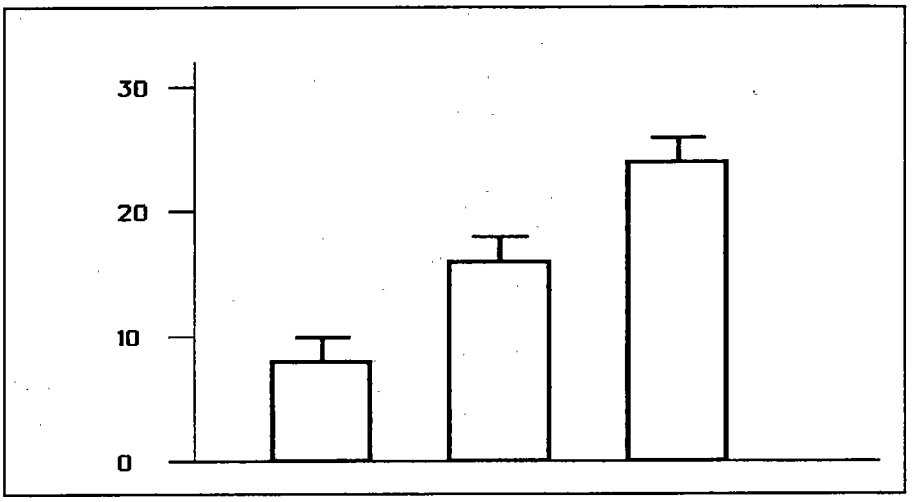

Fig.3. Dynamics of numbers of astrocytes in the sensomotor cortex of rabbits in controls (1), after 3 min (2) or after 1 hour exposure to SMF to animals' head.
Ordinate - number of astrocytes.

Since the glia plays an important role in the training and the memory we have investigated the influence the various EMFs on conditioned reflexes.

Under ordinary experimental conditions we most frequently observed the inhibiting effect of the EMF. Figure 4 shows the results of exposure to MW of

various intensity on mice. We can see that 10 $\mu W/cm^2$ MW have no effect on the preservation of T-maze reflexes. 250 $\mu W/cm^2$ MW disturb the memory. 1000 $\mu W/cm^2$ MW increase the repeated training intensity.

In more detail, the behavioural reactions to EMF were described in our book /Kholodov, 1975/ and were confirmed by other investigators /Sudakov, 1997/.

The set of the enumerated data testifies to the existence of a non-specific initial adaptive reaction of brain /NIARB/ which includes sensory indication of EMF, EEG reaction of synchronisation, glia reaction and inhibition of conditioned reflexes. The NIARB looks like stress /Salye, 1973/ or the reaction of activation /Garkavi et al., 1990/.

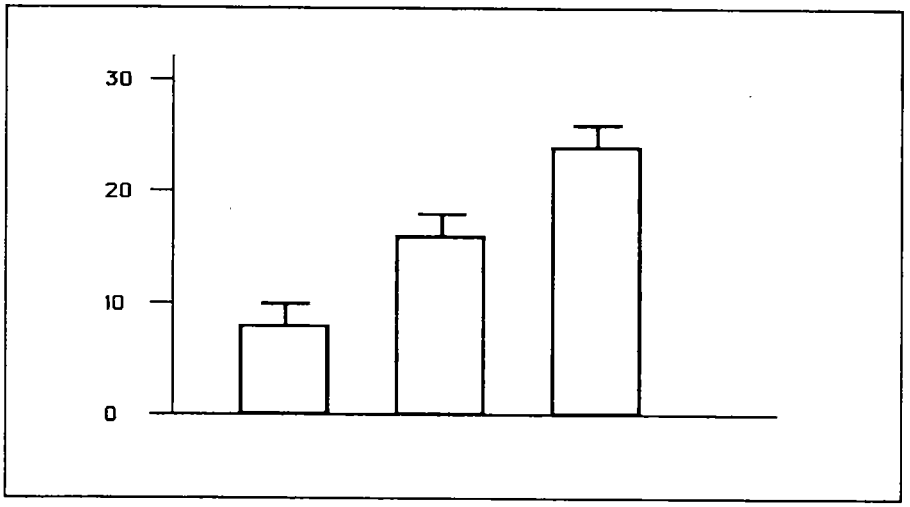

Fig.4. Effects of CW microwaves of 1000 (1), 250 (2) or 10 (3) $\mu W/cm^2$ on preservation of conditioned avoidance reflexes in mice.
Controls (4)

a - number of reinforcements during learning,
b - number of reinforcements during control.

In some cases, the EMF can increase the resistance of the body to various unfavourable influences. A future study of the NIARB might help in the solution of certain general problems of neurobiology.

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EFFECTS OF A MODULATED ELECTROMAGNETIC FIELD ON EMOTIONAL REACTIONS

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In our previous publications [1] it was shown that the areas the most sensitive to electromagnetic fields (EMF) of various ranges were limbic structures of the brain, in particular the hippocampus. The action of EMF on the body causes an epileptiform activity within these structures. It is known that limbic formations of the brain are the cerebral substrate of emotions [2], therefore it is logical to assume a certain relationship between emotions and the action of weak EMFs. It was in this connection that we conducted the present study. The aim was to discover possible effects of modulated electromagnetic fields (MEMF) on emotional reactions displayed by rats in different conditional reflex situations.

The subjects of the investigations were male and female rats of no particular breed. The MEMF source was a (modified in our laboratory) UVCh(UHF)-2 device generating EMFs with the carrier frequency of 30 MHz. They were sinusoidally modulated by a frequency which could be changed from 2 to 50 Hz with the aid of a 3G-10 sound generator. The depth of modulation was about 80%. The strength of the field to which the tested animals were exposed was 30-120 V/m. The strength of the electric component of the MEMF in the chamber, where the animals were placed, was controlled by a diode voltmeter with subsequent determination of the values according to the formula E= u/D, where u is the voltage measured on the capacitor plates, D is the distance between the plates in metres. Besides, control measurements of the filed strength were taken by an IEMP-1 device.

To generate MEMFs in the chamber containing the animals under investigation we used metal plates fixed along the front and back of the chamber and connected to a generator. The distance between the plates was 40 cm.

First of all we investigated the effects of MEMFs on the self-stimulation behaviour. Self-stimulation, as is known, is formed in animals in response to electric stimulation of positive emotiogenic structures of the brain. Bipolar electrodes were chronically implanted into different limbic structures - front, lateral and the hypothalamus, medial and lateral nuclei of the septum - of 30 rats. Irritation of the above brain structures with an electric current (voltage 10 - 12 V, frequency 55Hz, pulse duration 0.1 - 0.5 ms, duration of a pulse series 0.3 - 0.6 s)

caused self-stimulation behaviour of different degrees of expressivity in all the animals. The self-stimulation behaviour of the rats was studied in a chamber with two plates on the lateral walls. Between the plates we set up an EMF with the carrier frequency of 30 MHz modulated by 2.7Hz and 50Hz frequencies. The duration of the field action in all the experiments was 10 minutes.

As a result of the experiments conducted it was found that the action of an EMF with the modulation frequency of 2 Hz produced a 93% increase in the self-stimulation frequency within the first two minutes. Then the self-stimulation frequency dropped sharply and within 4 minutes completely disappeared. Under the action of an MEMF with the modulation frequency of 7Hz the self-stimulation was practically no different from the background value in the first two minutes and only thereafter, during 12 to 15 min, a reduction in its frequency was observed.

A 50Hz modulated EMF suppressed the self-stimulation in all the animals practically immediately. The above effects did not depend on the localisation of the tips of the irritation electrodes.

The experiments conducted have shown that MEMFs have a pronounced effect on positive emotional reactions of the animals. To find an answer to the question whether there are any differences in MEMF effects on conditioned reflex reactions of animals conditioned by a positive or negative reward, 28 rats were tested for peculiar behavioural features in the same experimental conditions with defence and food reinforcements. The tests were conducted in a special experimental chamber designed to develop conditioned food and defensive behaviour in rats in response to the same conditioned stimulus but in a different environment created by the change in the colour (black or white) of the back wall of the chamber. An electric bulb and a feeder were fixed to the left side wall. A brass grate through which electric current could be passed was embedded in the left part of the chamber floor. A conditioned food reaction was developed in rats, which had been deprived of food for 24 hours, with the white back wall of the chamber. As a result of the training, in response to switching on the light the animals rushed to the left side of the chamber where they obtained food in the feeder. Once the conditioned food reaction was acquired, the white back wall of the chamber was replaced with a black one and an electric current of threshold (30-50V) voltage causing a defence reaction in rats was passed through the grate. Under such conditions when the photic stimulus was activated the rats, making their usual way to the feeder, received an electrocutaneous irritation which they could avoid only by moving to the right side of the chamber. After two or three combinations of the photic and electrocutaneous stimuli with the black back wall in

place the rats developed a defensive reaction, i.e. in response to switching on the light the animals stayed on the right "safe" part of the chamber.

The rats' preliminary training was considered complete when a 100 percent adequate reaction was achieved in response to 10 exposures to the eliciting stimulus with both the white and black walls of the chamber. As a rule, the very change of the white wall for black provoked a distinctive defensive reaction - the rats hid in a corner, pressed themselves to the chamber floor, breathed hurriedly.

After the acquisition of the conditioned reactions we studied the peculiar features of manifestation of defensive and food conditioned reactions in the rats while under exposure to MEMFs. A 5 to 20 min MEMF exposure first of all disturbed the rats' defensive reactions. With that the animals in the defence situation (black chamber wall) in response to the eliciting stimulus insistently rushed towards the feeder in spite of receiving a strong electrocutaneous irritation (the average number of moves towards the feeder in response to a light flash was over 8; we observed one animal make as many as 24 attempts). During MEMF exposure a change of the white wall for black no longer induced a defensive reaction, like in the case with the intact animals. Food reactions in response to the eliciting stimulus in the presence of the white back wall were observed as before. However, certain changes in the animals' food behaviour were also detected in such cases.

The time of reaction to the eliciting stimulus (i.e. the time between the start of a stimulus and the eating of the food in the feeder) in the trained intact rats was sufficiently stable and showed almost no fluctuations (5.7 - 6.6+0.8 sec). Under MEMF exposure there was a sharp increase in the reaction-to-conditioned-stimulus time fluctuations (3.2 - 9.9+0.3 sec), though the difference in the mean values of the reaction times before and during the exposure proved to be statistically unreliable. Very typical for short-time MEMF exposures was the appearance of the animals' frequent motor reactions towards the feeder between two signals, something practically never observed in the intact animals. The above behavioural changes after a 5 to 20 min MEMF exposure were observed in 64% of the rats. A longer exposure of that kind also caused, in addition to the above-described changes in the defensive reactions, more pronounced and diversified disruptions of food reactions.

The experiments conducted point to the fact that MEMFs produce a mainly inhibiting effect on the conditioned reflex reactions formed on the basis of a negative (electrocutaneous) emotional reinforcement. To suppress the action of the

conditioned reactions formed on the basis of a positive emotional reinforcement a longer or more intensive MEMF exposure is required.

In the next series of experiments we studied the peculiar features of extinction of the conditioned food reaction in the rats exposed to MEMFs. MEMF effects on the development of extinctive inhibition of the conditioned food reaction were investigated on 30 rats. Conditioned food reactions were developed in all the tested animals. It is known that non-reinforcement of the conditioned food reaction produces negative emotional reactions in animals.

The experiments conducted have shown that MEMF exposure greatly hampered the development of extinctive inhibition in the rats. In five animals from the control group 5-8 non-reinforcements of the conditioned food stimulus caused the extinction of the conditioned reaction. Eight rats from that group required 8-10 non-reinforcements, while only two animals needed over 10 non-reinforcements. Six rats from the experimental group, for which the extinction was conducted under MEMF exposure, required 12-15 non-reinforcements, seven animals from that group 15-20 non-reinforcements, while two rats required 20 non-reinforcements of the conditioned food stimulus.

The average number of non-reinforcements of the conditioned food stimulus required to extinguish the conditioned food reaction in the rats exposed to MEMF almost doubled in comparison to the control group. A special series of experiments was conducted to study the peculiar features of the change in the reaction of MEMF exposed rats selecting the reinforcement side in a T-shaped maze. A special T-shaped maze was built for this series of experiments.

The rats, which had been deprived of water for 24 hours, were placed in the starting section of the maze with the exit blocked by a shutter. Bulbs were installed on both sides of the starting section. When one of them was switched on, it meant that the animal could obtain water either in the left or the right feeder of the T-shaped maze. Near each feeder there was a protective shutter which did not open unless the animal made, in response to the signal stimulus, the right choice of the reinforcement side. After a correct, or an incorrect, choice of the reinforcement side, the animals could return to the starting section.

A 50Hz modulated frequency EMF could be set up in the starting section by means of capacitor plates connected to a generator. It was activated simultaneously with the switching on of a signal bulb and terminated after the animal entered the central corridor.

Photocells were used to register the time it took an animal to pass through the maze. Only previously trained animals (those which for two or three experimental days prior to the exposure had displayed no erroneous reactions in the choice of the reinforcement side and whose latent period and total reaction time had stabilised) were exposed to EMFs.

The experiments were conducted on 18 rats. A day of MEMF exposure caused an average error rate of up to 18% in the choice of the reinforcement side in 15 rats. On the second and third day after the exposure one observed an average 11% reduction of the number of erroneous reactions. Later the number of erroneous reactions increased again to reach an average value of 15%. During subsequent experimental days the number of erroneous reactions in the rats constantly decreased, and by the eighth day practically all the animals fully recovered their ability to choose the correct reinforcement side.

Thus the experiments conducted point to a distinct effect of 50Hz modulated frequency EMFs on the emotionally coloured animal reactions aimed at satisfying the animals' basic biological needs.

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EXTREMELY-LOW-FREQUENCY-MF INFLUENCE ON THE BODY AS A SELF-ORGANISING SYSTEM

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The basic idea to consider a living system as a complex open non-equilibrium, non-linear and oscillating, i.e. self-organising, system has arisen from two fields of modern science: non-equilibrium thermodynamics (Prigogine I., 1964; Prigogine I., Stengers I., 1986) and synergetics (Haken G., 1985). Both of the lines offer an explanation of the facts that even weak fluctuations can radically alter the behaviour of the systems. They can result either in a decrease of the order and discord of homeostatic processes and in an increase of entropy, or, by contrast, in such coherent co-operative conversions that enhance the order and co-ordination of homeostatic processes and negative entropy. The importance of such an approach is obvious when appraising the influence of MF upon living systems. Indeed, the general trend of the processes towards the order or chaos is the basis for positive or negative influence of MF upon the body.

What types of co-operative processes occur at the organism level under the ultra-low-frequency MF (ULF MF)? According to synergetics, co-operative processes producing a modification of the functional state of the body are characterised by a multitude of variables of a state and by a limited number of parameters of order, that can be used for description of the state. The formation of a functional state of body as a result of co-operative conversions in response to weak stimuli is considered by us in the context of the theory of general non-specific adaptational reactions (GNARs) (Garkavi L., Kvakina E., Ukolova M., 1977, 1990; Garkavi L., Kvakina E., Ukolova M., Shikhlyarova A. Et al., 1984; Garkavi L., Kvakina E., Shikhlyarova A., Kuzmenko T., 1994; Shikhlyarova A., 1992; Kuzmenko T., 1994, et al.) From this theoretical standpoint the influence of ULF MF is realised on the level of organism as a self-organising system by the development of GNARs: the reactions of training (Garkavi L., 1969; Kvakina E., Ukolova M., 1969); of activation, both calm and heightened (Garkavi L., 1969, 1990) and of stress (Selye H., 1936), and of the states of reactivity corresponding to them. (Garkavi L., Kvakina E., Ukolova M., 1990).

Non-specificity of biomagnetic effects was always noted when the influence of EMF of diverse ranges was studied at the body level (Presman A.S., 1968; Plekhanov G.F., Kholodov Ju.A. 1982). This suggests that stress, according H.Selye, is the basis for the mechanism of MF action (Marino A., 1987), since stress had been the only known GNAR for a long time. In doing so it was not taken into account that stress (distress) is a GNAR to strong, unfavourable factors.

Because of this, stress contains not only features of protection, adaptation, but depression and even damage (Selye H., 1936, 1970). This is biologically warranted under exposures threatening life, and this is the reason why the stress reaction was fixed in evolution. H.Selye himself defined stress as a stereotypical reaction to a variety of widely different, by their specificity, factors, if they are strong enough - noxious. In fact, any agent of strong intensity (for a given organism) may be noxious and may cause stress. In relation to such stress Selye described a set (pattern) of changes in the body, among them the triad: thymico-lymphatic involution, decrease of adrenals, ulcers in stomach and intestines accompanied by lymphopoenia. It is precisely in this sense we use the term "stress'. Later H.Selye introduced the term "eustress", but didn't give a particular combination of variables in the body and the notion of the strength of an irritant became too broad and indefinite.

The chronic stress, now spread all over the world, decreases resistance very badly and forms a non-specific basis of a diversity of diseases of the 20th century. If any MF caused stress only, it would not be used for treatment.

The level of self-organisation in the body is lowered badly under stress reaction; the level of entropy is heightened. The energy-informative exchange with the environment is narrowed and the system becomes less and less open (Fig. 1). Resistance decreases and all this may finally lead to complete degradation and death.

Four types of GNARs emerged from our experiments with MF action at body level. Each of GNARs was characterised by a set of state variables and one and the same value of the parameter of order - percentage of lymphocytes in blood count. High correlation between the amount of lymphocytes in blood count and the set of state variables is shown, for example endocrine, immune and morpho-functional characteristics (Shikhlyarova A., 1985).

We investigated ULF MF from 0.1 mT up to 50 mT and from 0.001 Hz up to 1000 Hz. There were more than 8000 rats, adult (10-15 months), old (28-32 months) and tumour-bearing ones. More than 4000 people were also treated with MF. Taking into consideration the high sensitivity of brain and hypothalamus especially (Kholodov Ju.A. 1982) we exposed to MF the head first and foremost, and besides other parts of body considering the reflex impact. The exposure was carried out every day and varied from 10 sec. to 20 min.

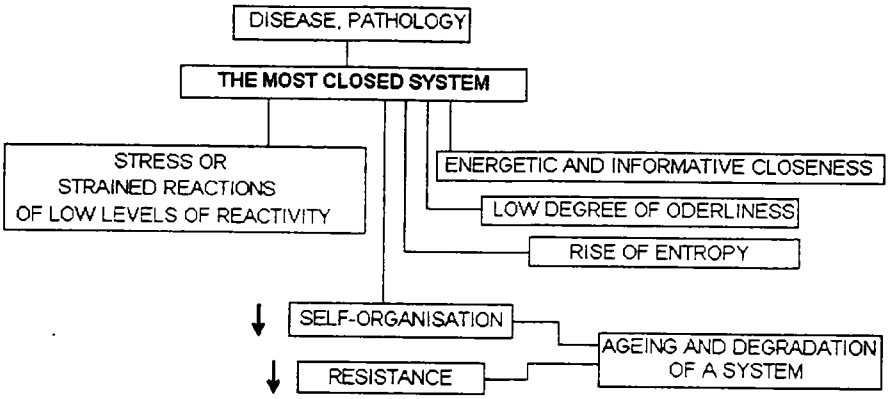

Fig. 1. Decline of self-organisation under stress and strained reactions at low reactivity levels.

Combinations of variables were distinguished in rats even after one exposure to MF of different biotropic parameters. Besides, the pattern depended upon the initial state. Along with the pattern of stress, a high incidence of the pattern corresponding to the description of activation reaction was revealed, namely a predominance of physiological (moderate) excitation in C.N.S. (instead of inhibition or overexcitation under stress), stimulation of lymphoid tissue in thymico-lymphatic system (instead of involution under stress) in the absence of hypersecretion of glucocorticoids, activation of thyroid and sexual glands and mineralcorticoid function which are suppressed under stress (Garkavi L., Kvakina E., Ukolova M., 1978, 1986; Garkavi L. et al. 1984; Shikhlyarova A., 1983). The percentage of lymphocytes in the differential blood count was increased to the upper boundary of the norm (instead of lymphopoenia under stress). In point of fact, the entire pattern was arranged within the upper half of the norm, excluding glucocorticoids which were within its lower half. Another pattern was revealed under the influence of MF. It corresponded to the combination of variables under training reaction which developed as a response to a variety of factors (like stress or activation reactions) but with a lesser intensity or biological activity. Most of the indices of the training reaction (excluding glucocorticoids) were arranged within the lower half of norm. Preventive inhibition predominated in C.N.S., there were no signs of suppression or stimulation of lymphoid tissue; activity of thyroid and sexual glands, secretion of mineralcorticoids and percentage of lymphocytes were within the lower half of the norm.

No rigid relation was established between the biotropic parameters of ULF MF and the character of GNARs. Therefore to maintain the same reaction it was

necessary to alter daily the "dose" (induction, frequency, exposure) correlating it by feedback with reference to the signal indicator of GNAR - percentage of lymphocytes (parameter of order). The parameter of order, and accordingly the entire pattern, of homeostatic parameters are changed when the type of GNAR changes in the points of instability. Thus, the process of changing of GNAR may be classified as a non-equilibrium phase transition (Kuzmenko T., 1994). Different GNARs correspond to "modes of stirring", by which steady cycles of work of complex systems are understood similar to the limiting cycles of simple systems (Molchanov A.M., 1992).

A closer look at all the data showed that with the induction of MF being increased by the same constant magnitude, the GNARs of training, calm activation, heightened activation and stress reiterate in the same order at different body reactivity levels (Garkavi L., Kvakina E., 1979), forming Periodical System of GNARs. We revealed the dose dependence of this kind later in studies of different other biologically active factors as well. The coefficient of GNAR is the value by which the dose needs to be changed in order to effect a transfer to the neighbouring GNAR. It varied from 1.1 to 1.2. The transfer from one reaction to another is discrete in character. With variation in frequency the dependence of GNAR development was more complicated but also periodical. With variations in exposure a distinct dependence was observed only within 20-30 min.

Hence, the homonymous GNARs may develop in response to different absolute values of induction, frequency and exposure, though training reaction develops in response to small influences, activation - to average and stress - to strong ones relatively to every given reactivity level.

Wherein lies the similarity and difference in the homonymous GNARs at different reactivity levels? The main characteristics of the GNARs at different reactivity levels are preserved, including the parameter of order. Relationships between main variables of state are preserved as well. However, the homonymous reactions have differences at different levels. GNARs of training and activation developing at superior levels are in harmony with synchronisation of functional activity of subsystems. Some signs of desynchronisation appear under stress only. As the reactivity level is lowering ("dose" is increased) the features of tension and desynchronisation are evolved and strengthened. It is most pronounced under stress. Thus, the homonymous GNARs with the changing of reactivity levels undergo a topologically invariant transformation (Kuzmenko T., 1994).

Similar regularities were obtained on the cellular level when studying the functional state of lymphocytes of peripheral blood, antioxidative system and

mitochondrial energetics (Barsukova L. et al., 1995; Barsukova L. et al., 1997; Shikhlyarova A. Et al., 1997) after exposure to MF of head and different parts of the body.

As mentioned above, the level of self-organisation correlates with the level of resistance and alters with a change of the adaptational reaction and of the reactivity level. When studying the ULF MF influence upon the body resistance in cancer-bearing rats, under toxic drugs and while ageing, we showed that the non-specific resistance is rising most effectively under the activation reaction of high reactivity levels. At the same time the periodical dependence of effects upon the parameters of MF is observed. Thus, under ULF MF up to 1 mT the resistance to the damaging action of chemo- and radiotherapy was the highest and similar to the resistance at high reactivity levels. Within the range from 0.1 up to 50 mT several optimums of anti-tumour effects on sarcoma-45 were observed: for example, 0.1-3.2 mT, 8.6 mT and 45 mT. In other experiments there were other optimums, but the non-linear effects always existed.

With the use of different frequencies, the difference between the influence on brain itself and on peripheral parts of body emerged. MFs with a frequency over 50 Hz were less favourable for head exposure (low reactivity levels) than MF of lower frequencies (higher reactivity levels). At the same time, MFs even up to 1000 Hz being used peripherally with relatively low induction (up to 10-20 mT) caused harmonical reactions of superior reactivity levels. A combination of different frequencies from 0.03 up to 9 Hz on the head with induction of 3 mT and on the tumour - about 500 Hz and 50 mT lead to the anti-tumour effect. Being combined with chemotherapy such influence protected from side effects and enhanced the anti-tumour effect of cyclophosphamide.

The influence of MF on non-specific resistance of tumour-bearing rats and under ageing is non-linear in character as well. However, weak MF markedly affected the resistance. The inhibition (under training reaction) and whole resorbtion (under activation reaction) of tumours were observed for a greater percentage (sarcoma 45, ascitic tumour of ovary, tumour induced by 3,4-benz-a-pyren) (Kvakina E., 1972; Shikhlyarova A., 1991; Garkavi L., Kvakina E., Shikhlyarova A., 1995). With chemotherapy, the percentage of tumour regression (ascitic tumour of ovary) increased to 100%, therewith protection of body from side effects was observed (Sheiko E., 1992; Garkavi L., Kvakina E., Sheiko E., 1994). The normalisation occurs not only at systemic level, but extends to cellular and subcellular ones. For example, luminescent-spectral characteristics of lymphocytes improved: ratio between uni- and bihelical nucleic acids - (synthetic activity according to V.Karnauchov) increased and its spectrum approached to the

norm; the ratio between histamine and serotonin in lymphocytes and polymorphs decreased (Sheiko E., 1992; Zhukova G., 1994); the energetic metabolism in mitochondria approached to the norm as well.

Similar results were obtained at the subcellular level in the study of energy exchange in the mitochondria of the liver and brain. Under the activation reaction induced by ULF MF a high level of exchange is observed and the processes of accumulation and consumption of succinic acid are balanced. Elements of misbalance appear only under stronger MFs or under higher frequency – i.e., at low reactivity levels. Under stress there is active consumption of succinic acid with elements of depletion, appearance of oxalacetic limitation of hyperactivity of succinic dehydrogenase. These disturbances increase significantly at low reactivity levels, the phosphorilation is either sharply stimulated (under acute stress) or badly inhibited (under chronic stress); requirements of succinic acid are unrequited (Barsukova L. et al., 1995).

ULF MF, promoting harmonical anti-stress reactions of activation (especially enhanced one), induced rejuvenation of old rats.

The modes of applying MF for treatment of cancer in humans were developed for both independent use (cancer of skin and lower lip, Patent No.522688) and for use in combination with traditional methods (Garkavi L., Kvakina E., Ukolova M., 1990). We have managed to obtain enhancing of anti-tumour influence and decrease of side effects of chemotherapy and X-radiation.

An analysis of the patterns of anti-stress GNARs of training and especially of activation under weak stimuli (at high reactivity levels) and of the states of areactivity corresponding to them showed that such states are characterised by a high level of synchronisation, resistance and orderliness, maintained due to an active interaction with the environment (Fig. 2). That is why these reactions are the non-specific basis of the norm and health (Garkavi L., Kvakina E., 1996).

From the standpoints of synergetics and of the theory of cognitive dynamic nets it is clear that such a complex system as the organism has a definite set of attractors – stable states in the phase space of possible functional states of a system. It is important for different influences applied (including MF) to induce such changes in the processes of the homeostasis which would lead to attractors characterised with high resistance and orderliness. In order to purposefully exert such influences it is necessary to know the whole spectrum of functional states (set of attractors) and the appropriate laws. From the point of view of the theory of adaptational reactions such a spectrum is presented by the Periodical System of

adaptational reactions. The System allows to understand how to vary the parameters of MF in order to come into the area of a definite attractor (a stress-inducing one with the degradation of the system, an activating one with the evolution and self-organisation, or some intermediate one).

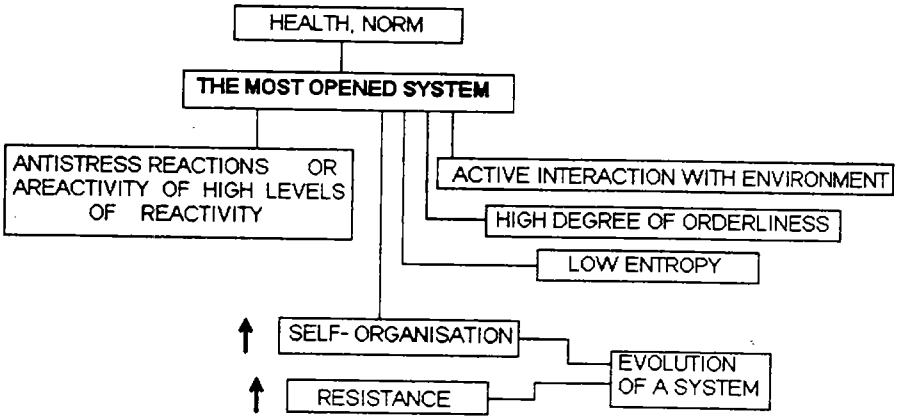

Fig. 2. Enhancement of self-organisation under activation and training reactions at high reactivity levels.

Living systems are able to defend themselves from damaging strong stimuli owing to the fact that they are far from the equilibrium state and can react upon weak stimuli in the presence of damaging ones. Only weak and adequate ULF MF (i.e. MF inducing antistress reactions) assist the evolution and self-organisation. On the contrary, strong or technogenic pollution factors break down the processes of evolution and self-organisation inducing unfavourable adaptational reactions of low reactivity levels.

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AN ANALYTICAL SURVEY OF THEORETICAL STUDIES IN THE AREA OF MAGNETORECEPTION

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There is no simple answer to the question of how a weak, about 1 *G* and less, low-frequency magnetic field (MF) causes a biological response. Processes of different hierarchic levels of a living organism, from molecular (bio)physical to complex adaptive biological processes, contribute essentially to the magnetobiological effect (Kholodov *et al*, 1992). In biophysics, separate magnetosensitive processes at the fundamental level of interaction of fields and substance are studied. It is exactly at this level that complex spectral or «window» modes of the relation between biophysical processes and biologically significant EMF parameters do originate.

There are different kinds of explanations of magnetobiological effects (MBE). This leads to a variety of conventional classifications of models in magnetobiology (Polk, 1991; Adey, 1993; Berg *et al*, 1993; Blank, 1993). The presence of different classifications, their ambiguity and rapid obsolescence reflects the difficulties in explaining the MBEs, their paradoxical character and the lack of knowledge of their physical nature.

Today, by way of further development of the ideas in the indicated reviews, it is reasonable to single out the following kinds of physical processes or ideas hypothetically underlying the primary mechanisms of biological magnetoreception.

- Biomagnetite in MF and ferromagnetic contamination
- Eddy electric currents, induced by alternating MF
- Classical and quantum oscillator models
- Cyclotron resonance in magnetobiology
- Interference of quantum states of bound ions and electrons
- Coherent quantum excitations
- Biological effects of torsion fields accompanying MFs

- Biologically active metastable states of liquid water that are susceptible to MF variations
- Magnetosensitive free-radical reactions and other «spin» mechanisms
- Parametric resonance in magnetobiology
- Stochastic resonance as an amplifier mechanism in magnetobiology and other random processes
- Phase transitions in biophysical systems displaying liquid crystal ordering
- Bifurcation behaviour of solutions of non-linear chemical kinetics equations
- «Radio-technical» models, in which biological structures and tissues are portrayed as equivalent electric circuits
- Macroscopic charged vortices in cytoplasm

The depth of elaboration of the above-listed ideas in literature varies significantly. The predictive mathematical models only support several ideas.

Historically, one of the first ideas in the area of magnetobiology was an idea of the so-called biogenic magnetite. There are natural microscopic crystals, usually of magnetite, within the body of some animals and bacteria. They are capable of being magnetised. An external MF influences such crystals so that they tend to change their orientation. Consequently, the crystals exert pressure on the adjacent tissue and cause a biological response. In a number of cases, it is possible to explain by this manner the biological reception of a weak static MF (Kirshvink *et al*, 1992). Microscopic crystals of magnetite were found in the brain of some birds, which are known to navigate well in the geomagnetic field. Traces of magnetite are also found in some insects.

An explanation of the ELF MF effect on cells in vitro based on the ferromagnetic contamination (Kobayashi *et al*, 1995) develops the biomagnetite idea. Small polluting magnetic particles are present not solely in the air dust. They are also deposited on the surface of laboratory devices, and penetrate into plastics and glass, into chemicals and purified water. Their mean size is about 10^{-5} *cm*. The particles consist of ferro- and ferrimagnetics, that is, possess spontaneous magnetisation. The authors have shown that routine laboratory procedures like

pouring or and rinsing give rise to an enrichment of the cell cultures by pollutants. The number of particles in the cultures could be 10 times more than that of cells. The energy of such a particle is approximately three orders of magnitude greater than *kT*. In the authors' opinion, the magnetic particle absorbed by a cell membrane can transfer its energy to the adjacent biophysical structures, for example, mechanically activated ion channels.

These mechanisms of MBE stand apart and do not solve the basic problem of magnetobiology. Indeed, many unicellular organisms, wherein magnetite is absent, are capable of reacting to the MF. The reaction in many cases is of a complex non-linear, depending on the MF parameters, character. The basic problem of magnetobiology is exactly in the explanation of this phenomenon, which is a paradoxical one from the viewpoint of orthodox physics.

Low-frequency MFs induce eddy electric currents in biological tissues. They can also cause biological effects. In general, the magnitude of the current follows the electric field strength, which is directly proportional to the product of the AMF amplitude and frequency. If the hypothesis is true, there must be a correlation between MBE and that product. Indeed, there is experimental evidence that such a correlation appears with the growth of the MF amplitude (Lerchl *et al*, 1990; Schimmelpfeng *et al*, 1997). However, no correlation has been observed for relatively weak, like geomagnetic, MFs (Juutilainen, 1986; Liboff *et al*, 1987; Ross, 1990; Blackman *et al*, 1993; Jenrow *et al*, 1995; Prato *et al*, 1995). So, in (Ross, 1990) the MBE in a certain frequency window was invariant even with a 40-fold change of the induced currents. This points to the existence of primary mechanisms irrespective of eddy currents.

The informational character of the action of weak physical and chemical factors on biological systems is frequently discussed in literature. In this regard, a biosystem is assumed to be in the state of unstable equilibrium. Therefore, only a weak stimulus is required to put the system in a new state, at the expense of its intrinsic energy resources. In other words, the so-called biological amplification of a weak MF signal takes place. Chemical kinetic equations are used for the phenomenological description of this process. Under certain conditions, their solutions demonstrate a bifurcation behaviour, the transition under weak disturbance into a qualitatively different dynamic mode (Kaiser, 1996).

Thermal fluctuations of the *kT* scale are ten orders greater than the quantum of the AMF energy. In this case, the question is important - why do these random disturbances not destroy the MBE? A solution of the problem is suggested which is related to the idea of coherence of the external stimulus, against the background of

an incoherent thermal noise. Then a high quality molecular oscillator may be swung up (time coherence) to a condition, in which its energy will be sufficient for an initiating push. In addition, a system of oscillators may be swung up, in a time-space coherent manner, so that the quantum of a collective excitation will be released (Frohlich *et al*, 1983; Popp *et al*, 1979). Different microscopic objects were suggested as oscillators interacting with MF: charged molecular groups, plasmatic membranes, and whole organelles. It is significant that neither the idea of a biological oscillator, nor the idea of collective excitations have resulted in verifiable theoretical mechanisms in the ELF MF range yet. At best, time and amplitude threshold for the microwave exposure is predicted, which is necessary for a biological response to occur (Wu, 1996).

One more idea to overcome the thermal factor appeals to the so-called stochastic resonance. The phenomenon consists in strengthening of a small signal against the background of a noise, at the expense of energy redistribution within the frequency spectrum of the signal-noise mix. It is crucial that the noise here is a useful feature of the system, not an embarrassment. In the case of a stochastic resonance, relatively weak physical or biological signals can cause essential dynamic changes, against the background of many disturbing factors. In (Wiesenfeld *et al*, 1995), the response of a crayfish mechanoreceptor cells to an acoustic stimulus, in the form of the mixture of a subthreshold signal and a Gaussian noise, satisfied attributes of a stochastic resonance. The phenomenon was made use of for solving kT problem in magnetobiology in (Makeev, 1993; Kruglikov *et al*, 1994). However, only about 100 fold strengthening was really achieved, with the loss of the quality of the signal and its time coherence (McNamara *et al*, 1989). Such values are obviously not enough for the explanation of the biological efficacy of weak ELF MFs.

The rate of some free radical reactions depends on the value of SMF (Buchachenko *et al*, 1978). The probability of the product creation from a pair of radicals, which carry spin angular momentum, depends on their net spin momentum, that is, on the mutual orientation of their spins. A static MF influences the probability of a suitable orientation, thus shifting the biochemical balance. At the same time, this mechanism does not possess frequency selectivity. The lifetime of the radical pair until reaction or, on the contrary, until dissociation, that is, when the bound couple of radicals are susceptible to MF, is of the order of 10^{-7} sec. The pair perceives the ELF MF as a static field; no resonance does appear. Therefore, for explanation of the frequency and amplitude windows in MBE, the magnetosensitive free radical reaction is assumed to be a link of the complex non-linear system described by chemical kinetic equations with bifurcation (Grundler *et al*, 1992; Kaiser, 1996). Difficulties of this group of models stem from the primary

MF influence on the radical reaction rate. There is a set of physico-chemical reasons that restrict susceptibility of the rate to MFs by quantities of the order of 0.1% per G. It is not enough for MBE to be explained in a reliable manner.

In a number of cases, the effects of weak MFs are resonant in character, and the effective frequencies are close to cyclotron frequencies of ions Ca^{++}, Na^{+} and others. It has given the basis to assume that a cyclotron resonance underlies the observable phenomena. Many authors developed the theme of such resonance in magnetobiology. Nonetheless, it has not received recognition due to the lack of correct physical substantiation. At the same time, these experiments showed the essential role of ions, especially Ca^{+}, in magnetobiology.

To overcome weakness of the cyclotron resonance idea, macroscopic charged clusters or vortices, formed by bunches of ions in biological plasma were postulated (Karnaukhov, 1994). These targets for MF effects were chosen because of their relatively large own energies, which may be comparable to kT. Then, even a weak MF can change significantly the energy of a vortex bearing, for example, a macroscopical electric charge. Yet, strictly determined conditions of the vortex movement are needed. In particular, the movement of the centre of mass must be characterised by an angular momentum, otherwise MF can't deliver energy to the moving object (Binhi, 1995). It is doubtful if such a motion is real for a macroscopic object like vortex in bioplasma. Moreover, the comparison between the energy of a vortex and kT makes sense only with the existence of a conversion mechanism for that vortex energy to be transformed to the energy of a separate degree of freedom, that is, to the microscopic level. It is difficult to visualise such a mechanism. In addition, the physical nature of molecular forces, which could provide the existence and stability of the aforementioned clusters and vortices, is unclear.

Some biological effects of the MF modulated on its magnitude reveal windows of efficiency when scanning the frequency and the amplitude of the AMF component. Frequency and amplitude spectra of MBEs are rather informative in terms of revealing the primary physical mechanisms of magnetoreception. For explanation of the MBE spectra, there were used different conversion mechanisms of the MF signal at the level of microscopic dynamics. Classical and quantum models of the ion binding by some proteins were studied in (Chiabrera *et al*, 1987; Chiabrera *et al*, 1991; Lednev, 1991; Zhadin, 1996). The biological activity of some proteins depends on whether or not the ion is bound with the protein. The value of MBE was assumed to vary approximately as the intensity of ionic quantum transitions. The MF was supposed to affect this intensity. However, collinear static and AC MFs affect only phases of wave functions, and do not really

cause transitions in the Zeeman sublevels, or change the intensity of such transitions induced by other factors. The population of each quantum state remains exactly constant regardless of the MF parameters. In spite of this, it was possible to demonstrate in (Lednev, 1991) the similarity of the amplitude spectra of some MBE and those of the effect of parametric resonance in atomic spectroscopy. The last resonance deals with quantum transitions (for example, Alexandrov *et al*, 1991). This entailed a number of publications (Blanchard *et al*, 1994; Lednev, 1996), which did not clarify the relationship, though. The authors call the above-indicated controversial mechanisms parametric resonance of bound ions.

In (Binhi, 1997; Binhi, 1997a), the known phenomenon of the interference of quantum states is involved for explanation of the physical nature of magnetoreception. MF, which is varied in its magnitude, not in direction, changes only the phases of ion wave functions. It is an interference that connects phase changes to physical observables in quantum mechanics. The interference of quantum states was observed in physical measurements either for free particles, including relatively heavy particles up to atoms, or for bound particles. In the latter case, the interference was observed only indirectly, through the characteristics of re-emitted electromagnetic fields. It reduced particles, suitable for the interference manifestations, to electrons in atoms. It has been suggested that the interference of bound heavy ions is also observable, by means of indirect biological measurements, with involvement of natural active biophysical structures (Binhi, 1997). This idea finds corroboration (Binhi, 1998; Binhi, 1998a) in a good agreement with known experiments. The interference of bound ions may be regarded as a hitherto unknown physical effect detectable in principle only by means of biochemical or biological measurements. The interference of quantum states in atomic spectroscopy is related with coherent quantum transitions in atomic electron levels and is not related to the internal structure of electron wave functions. At the same time, it is the internal structure of ion wave functions that the ion interference is based on, even in the absence of any quantum transitions. As of today, the ion interference mechanism predicts polyextreme effects of the following cases:

a) magnitude/direction modulated MF

b) magnetic vacuum

c) static MF with allowance for their own rotations of ion-protein complexes

d) pulsed MF with an DC MF as the background

e) MF of the NMR frequency subject to spin degrees of freedom of ionic isotopes

f) the interference of states of a quantum rotator with distributed charge as the model of amino acid molecule

g) weak AC electric fields

h) the shift and splitting of MBE spectral peaks under the rotation of biological samples.

Appropriate biological effects, except for the last, were really observed in experiments. The formulas provide the dependence of the ion-protein dissociation probability from the MF parameters, the frequency of the AC component, the amplitudes and mutual orientation of the AC and DC components. Significant features of the MBE spectra calculated after the mechanism depend on masses, charges, and magnetic momenta of the involved ions. In most of the cases under study, ions of calcium, magnesium, zinc, and hydrogen and sometimes potassium appeared to be relevant.

One of the primary MBE mechanisms associates MF effects with altered states of liquid water in biological media (Fesenko *et al*, 1995; Binhi, 1992; Konyukhov *et al*, 1995). The changes in water are a consequence of the external field influence; they are transmitted further to the biological level at the expense of water taking part in a variety of the metabolic biochemical reactions. It is unclear today, what is it exactly in liquid water that could be the target for MF action? In (Fesenko *et al*, 1995a), the stable water-molecular clusters were discussed based on observed low-frequency spectra of the water electric conductivity. The clusters were assumed to memorise an electromagnetic activation. The stable changes in structure properties of water were observed in (Lobyshev *et al*, 1995) using the UV luminescence spectrophotometer. They have been attributed to different water structure defects that include specific centres of luminescence. Alterations in the biological activity of liquid water were found in (Rai *et al*, 1994) with the static MF influence, in (Akimov *et al*, 1998) after the influence of a domestic TV. In (Binhi, 1992), the nuclear proton spins were considered as primary targets of MF. The metastability of water states was associated with microscopic orbital currents of protons in water-molecular hexagons, and the deviation from the right stochiometric composition of water. Existence of these states is verifiable in relatively easy experiments (Binhi, 1998b). The memory of water effects, interacting with EMF, were observed in (Sinitsyn *et al*, 1998) in radio-frequency

spectra. The effect was supposed to originate from the oscillations of water-molecular hexagons.

An increasing number of investigations demonstrate that very weak MFs, at the level 0.1 G and less, can also affect biological systems. These data, schematically depicted in the Figure, are of significant concern because they are hardly consistent with any of the proposed mechanisms. It poses the question of physical constraints defining the possible fundamental nature of the biological effects of hyper-weak MFs. Figure shows several theoretical limits of different mechanisms and descriptions of EMF bioeffects. The kT and thermal limits are well known. The last was derived repeatedly in many scientific researches and works on EMF standardisation. The quantum electrodynamics limit needs further comment.

Interaction between EMF and a substance is classified within the different types of description, classical or quantum, both of EMF and field of matter. The most of supposed primary mechanisms applies classical material particles interacting with classical EMF, a wave field. Recent predictive mechanisms, which use the quantum description of ions in classical EMFs, are based on the so-called semiclassical approximation. QED sets conditions for a classical EMF description to be valid: populations of states of EMF oscillators must be sufficiently large compared to unit. It follows the relation that links the frequency and the classical amplitude of the magnetic EMF component: $H > (\hbar c)^{1/2}(2\pi/c)^2 f^2$. This limit, the lower inclined line, is shown in Figure. As is seen, all "low frequency" effects but the hyperweak MM radiation effects do require only classical EMF description. However, this does not set the minimal intensity of EMFs detectable by biological systems. The natural constraint on the electromagnetic susceptibility of the biological reception, as well as that of any receiver of the physical nature, relates to general QM lows.

There is the relation $et > \hbar$ between the minimal energy change e and the time t required for its registration. Consequently, for example, an ELF EMF photon of the frequency f to be registered by any system, including biological one, the time $t=1/f$ is to be spent, at least. At the same time, this relation also does not set a lower limit of the susceptibility to EMFs.

There are enough prerequisites, both theoretical and experimental, to assume the existence of so-called torsion fields, see references in (Akimov *et al*, 1995; Shipov, 1993 and 1997). These long-range geometric fields can propagate independently and accompany EMFs too. The scientific area of geometrisation of physical fields has been in existence since the last century. The general object of

new theories, particularly (Shipov, 1993), is torsion fields, which stem from the known geometrical property of the space-time - torsion. Mathematically, they are tensor fields that describe the curvature of space and the Ricci torsion, not the Cartan torsion like in ordinary torsion theories. All the known fundamental fields and their equations appear here as some limit cases of the more general equations of torsion fields. Torsion fields originate particularly in spins of microparticles. Non-linear extensions of the known fundamental equations, describing «torsion effects», may be derived from the general equations of torsion field. Note that torsion fields do not alter the energy of a quantum system involved in the interaction. They influence only phases of the system wave functions. In this case, a charged particle like the ion in a protein cavity interacts with AC torsion field in a resonant manner. The energy is not an adequate attribute of torsion fields. In particular, they do not obey the law of the reciprocal square. Therefore, the notion of a magnitude is not specified regarding torsion fields: weak MFs affect biological systems via the torsion fields generated by those MFs (Akimov *et al*, 1997).

Apparently, there are no general theoretical constraints defining a lower limit for the intensity of EMFs affecting biological systems. All the physical constraints suggested to date are based on the proposed specific primary mechanisms of EMF signal transduction, not on the first physical principles. Only the microscopic design of the biological receptor and the time of its coherent interaction with EMF define the level of hypersensitivity in each specific case. It is essential that the time of coherent EMF interaction with biosystem may be long enough to cause effect due to the state of living matter which is far from the thermal equilibrium.

Torsion field physics apart, the most important and equally paradoxical problems concerning MFs of the geomagnetic level, are as follows. 1) A mechanism or process of conversion of the MF signal to the biochemical response, whose energy scale kT is ten orders greater than the quantum of ELF MF energy. 2) Why thermal fluctuations of the same order kT do not destroy the indicated weak signal conversion. At first sight, the paradox of the second problem is much more drastic, because an «obvious» solution of the first one is in the signal energy storage or in the signal amplification. Therefore, the main attention was paid to the solving of the second problem, with the almost arbitrary choice of the conversion mechanism. However, it is the conversion mechanism that the description of «window» polyextreme spectra depends on. This mechanism defines the predictive force of the model. Thus, as of today, there are no *predictive* models solving both the problems simultaneously. At the same time, predictive models (Binhi, 1997, 1998) have appeared; and they solve the first problem. This characterises the current state of theoretical studies in the field of magnetobiology. The predictive

force of such models means that the biological effects of weak MFs, as an important ecological factor, are becoming predictable as well.

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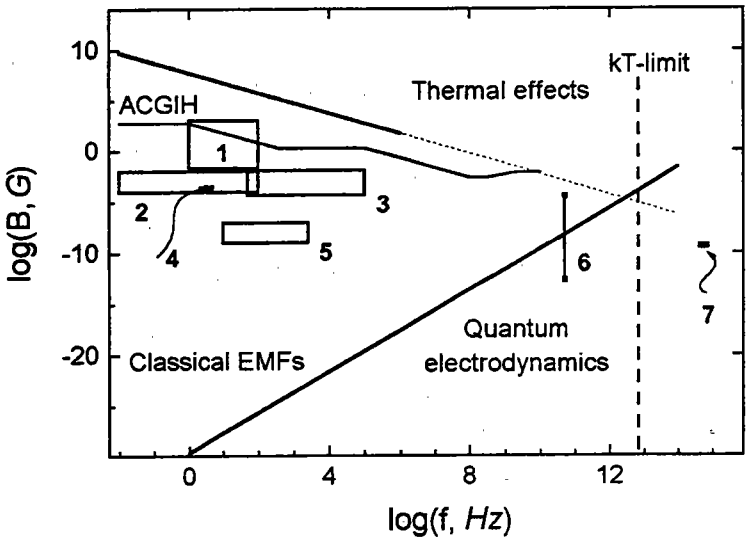

Figure. The figure illustrates various limits and areas of EMF biological effects as functions of two variables, EMF frequency f and amplitude B. The large scale of both the variables is chosen to show qualitatively different cases of the effects and theoretical approaches. A quantum of EMF energy is less than kT to the left of the dashed vertical line. This line defines a paradoxical area, wherein the biological effects are not possible from the orthodox viewpoint. The top downward line separates very approximately areas of thermal and nonthermal EMF bioeffects. The lower upward line is the QED limit. EMFs are to be described as a quantum object below this line. The step-inclined line is the ACGIH limit for the safe levels of the EMF exposure. Seven areas marked by digits mean ranges of parameters of: **1** – ELF EMFs used in most of magnetobiological experiments; **2** – EMFs produced by magnetic storms that are known to correlate in time with peaking of cardiac-vascular diseases; **3** – background EMFs produced by the variety of home appliances, video display terminals such as TV and computer monitors; **4** – MFs that affect some amino-acid solutions (Fesenko *et al*, 1997); **5** – MFs calculated at 0.5 m from the TecnoAO protective device, Tecnosphere, France, patent No.93/00546 (Youbicier-Simo *et al*, 1996, 1998), which protects against harmful VDT irradiation; **6** – EMFs below a quantum electrodynamics limit, used in (Belyaev *et al*, 1996), that significantly affect cell culture; **7** – susceptibility threshold of the human eye. As is seen, almost all the magnetobiology falls into the paradoxical area, to the left of kT limit. Semiclassical approach might be sufficient to describe MBEs. However, the absence of the predictive primary physical mechanisms for MFs as small as 10^{-3}–10^{-10} G makes it attractive to apply the torsion field physics for the MBE explanation.

ON THE SENSITIVITY OF LIVING ORGANISMS TO SUPERWEAK ELECTROMAGNETIC WAVES IN THE MILLIMETRE RANGE

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1. Introduction

Electromagnetic (EM) waves are of primary importance in vital activity processes [1-3] which comes as no surprise since the terrestrial life owes its origin to electromagnetic radiation (EMR) of the Sun. Every second the Sun emits an enormous quantity of radiant energy - $3.83 \cdot x\ 10^{23}$ kW (Sun's luminous emittance) into space [4]. Almost the entire solar radiation energy is contained in the continuous spectrum within the wavelength interval from λ_1 = 1500 Å (ultraviolet rays) to λ_2 = 5mm (millimetre radiation). The Earth's share is approximately 5×10^{-10} of that solar radiation, i.e. $19 \cdot x\ 10^{13}$ kW, which is a huge amount. An integral flux of solar radiation passing through a unit area perpendicular to the direction of sunrays beyond the terrestrial atmosphere, with the average distance between the Earth and the Sun being approximately 150 million km (astronomical unit), is about 1.37 kW/m^2 [4]. Almost half of that energy is absorbed or dispersed by the terrestrial atmosphere and, for example at the latitude of Moscow near the ground surface on a clear summer day (Sun at zenith), the summary radiation is $\approx$ 700 W/m^2. The distribution of this energy in the above-indicated wavelength range is very irregular, with the maximum radiation within the infrared wave area (λ = 430...500 nm), while the total share of infrared and ultraviolet waves in the optical wave range (λ = 400...10 nm) is about 60% of the electromagnetic energy of the Sun.

At the average spectral density of EMR of the Sun

$$P_1 = 700\ W / \delta f_{1\text{-}2} = 3{,}5 \cdot x\ 10^{-4}\ \mu W / (MHz \cdot cm^2),$$

where $\delta f_{1\text{-}2} = f_1 - f_2$; $f_1 = c/\lambda_1$; $f_2 = c/\lambda_2$; c - velocity of light;

in the millimetre (mm) wavelength range the spectral density of solar radiation near the ground surface (near λ = 8mm) $P_2 \approx 10^{-13}$ μW/ (MHz· cm^2) [5].

Thus the difference between P_1 and P_2 is approximately 9 orders of magnitude (!).

2. On the sensitivity of biological objects to electromagnetic radiation

In the process of organic evolution on Earth different biological objects followed different paths of adaptation to solar EMR, making use of different sections of the frequency range to obtain information about their environment (visible range - visual apparatus), to sustain vital activity (heat - infrared waves). At the same time special mechanisms were developed for protection from other «harmful» EM waves (for instance, pigmentation - to obtain protection against ultraviolet waves) etc.

With a mind-boggling effectiveness use was made of the visible range of EM waves (λ = 400...740 nm) - to form visual sensations and to analyse its spectral composition - colour perception, thus creating an emotionally saturated perception of the world. Perception of different colours corresponds to different wavelengths (frequencies) of EMR - from violet (λ = 400 nm) to red (λ = 740 nm), while the visual apparatus itself performs the role, to use a radio engineering analogy, of a wavemeter (frequency meter), with the CNS section responsible for the formation of colour perception performing the function of the indicator [6].

Recent years have seen a lively debate in scientific publications concerning the problem of biological significance of EM waves in the MM (or extremely high frequency (EHF)) range [7,8]. This range attracted researchers' attention in mid-1960s when, through the efforts of mainly Soviet (Russian) scientists, [9] this frequency range, which had been the last «white spot» on the EM wave scale, was fully investigated. It was also in those years that an original concept was advanced concerning a possible great biological significance of MM waves [10]. This pioneering idea later corroborated by experiments led to the discovery of a new method of treatment of different human and animal diseases (MM- or EHF-therapy) and to the development of a new kind of medical equipment.

The basic idea explaining a possible mechanism of the effect of low-intensity, non-thermal MM waves on living organisms is to the effect that natural oscillations of plasmatic membranes of living cells lie exactly within the EHF range [11-13]. Sustaining such oscillations in cells due to their own metabolism (or due to external irradiation - EHF therapeutic device) is the basic condition of functioning of a living cell.

Another idea is to the effect that a key role in the response of biological structures to external EMR in the MM range is played by water which is the most powerful absorber of such waves. Thus, for instance, a flat 1-mm water layer

weakens the power of MM radiation 100 times at $\lambda = 8$ mm and 10^4 times at $\lambda = 2$ mm [14, 15].

Considering all the above-mentioned, it seems important to make an evaluation of possible sensitivity of living organisms in the MM range of wavelengths.

3. On a certain approach to the evaluation of the sensitivity of biological objects to MM-waves

The therapeutic apparatus widely used in medical practice make use of a power density of about 10^3 $\mu W/cm^2$. The power densities registered as threshold values in biological experiments were: $\approx$ 500 μW in studies of imperceptible perspiration [16] and even $\approx$ 1 μW in studies of convection in thin liquid layers [17].

These values are significantly greater than the self-radiation of biological objects in the MM range. For example, at the room temperature T = 293K and λ = 8 mm in the 1MHz frequency range, during time $t \cong 1$ sec and with the «skin-air» reflection coefficient = 0.5, own thermal radiation is determined according to the following formula [5]

$$P_{own} = (1 - R_{refl.}) \cdot kT\delta f / (t \cdot \lambda^2) = 10^{-16}\ \mu W/cm^2.$$

This value is significantly smaller than the solar EMR near the ground surface in the MM range. The 10^{-16} $\mu W/cm^2$ value is evidently the lower limit (threshold value, $P_{thresh.}$). Once this value is exceeded, a response from the biological object in the MM wavelength range is possible. Then, to use a radio engineering analogy, one should ascribe the sense of the biological object's own noise (noise power) to the P_{own} value, and the «input» (threshold) signal to the external EHF signal power.

Coming back to the «historic» argument over the problem whether MM radiation, whose radiation quantum $h\nu$ is less than the thermal-motion energy kT, can affect biological objects, it is more logical to proceed not from the correlation $h\nu << kT$ but from the correlation $P_{thresh.} = P_{own}$.

4. Conclusion

While evaluating the threshold sensitivity of bio-objects to external EMR in the MM range one should be guided by the value power density $P_{thresh.} =$

10^{16} μW/cm^2 (in the 1MHz frequency band). This value can be even somewhat lower if such (well-known in radio engineering) effects as synchronous detection or coherent accumulation of signals, as well as regenerative or super-regenerative amplification, can be realised in the bio-object in question.

Realisation of the threshold sensitivity of bio-objects to MM radiation can be easier at those frequencies for which the damping of MM waves in an aqueous medium is minimal, e.g., for f = 50.3; 51.8; 65.0 GHz[18, 19].

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PECULIARITIES OF BIOLOGICAL EFFECTS OF ELECTROMAGNETIC NON-IONIZING RADIATION AT CELLULAR AND MOLECULAR LEVELS

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Survey of published literature. Radiobiology of non-ionising electromagnetic radiation deals with one still unsolved fundamental problem - whether the biological effects induced by such radiation are due solely to thermal damage or some non-thermally produced damages also occur. The problem exists both for unicellular and pluricellular organisms. It is now recognised that such a simple classification is neither general nor sufficient. Evaluation of the published studies is complicated due to the variety in exposure equipment, irradiation conditions, the biological objects involved and the effects registered. All researchers agree that heat does play a critical role in most of the effects observed. It is true that the temperature needs to be carefully controlled in the execution of experiments related to biological effects induced by non-ionising electromagnetic radiation.

Thermal effects. Cultures of various unicellular microorganisms were often used to distinguish the effects produced by conventional thermal responses from those of microwave energy. There is obvious evidence of thermal effects of microwave radiation at high power density. A large number of published papers point to the absence of biological effects until microwave energy causes an appreciable elevation of the temperature of the cell suspension exposed (Biological Effects..., 1986). A large body of papers shows that cell death would occur only when lethal temperatures were reached (Ward *et al.*, 1975; Sapareto *et al.*,1982; Millar *et al.*, 1984 and many others). The results of these studies indicate that cell responses to microwave irradiation can be observed solely at heat induction and that no biological effects are possible without elevation of temperature. On the basis of these data, it was concluded by some authors that over a wide range of frequencies and power densities there appear to be no biological effects of electromagnetic fields either at cellular or molecular levels not attributable to elevated temperature. By the way, the assumption that the only hazardous effect of microwave radiation is dielectric heating of tissue has been the guideline for the standard for the EMF MPL of human exposure in the USA and many other countries (Klauenberg *et al.*,1995).

Specific non-thermal effects. Although it is generally accepted that the major effects of microwaves on biological systems are thermal in nature, the possibility of non-thermal specific biological effects from non-ionising electromagnetic fields cannot be excluded. Some authors postulated that factors other than thermal effects might be involved in the effects of microwave irradiation on unicellular organisms at cellular level. Heller and Teixeira-Pinto (1959) observed chromosomal aberrations in onion root-tips growing in water when exposed to 27-MHz field. They ruled out the effects of heating because of short pulses of radiation. Chen *et al.* (1974) exposed mammalian cells *in vitro* to 2.45 GHz fields at intensities of 20 to 85 mW/cm^2 for the duration of 4 to 20 minutes. Chromosomal aberrations were induced by microwave exposure while conventional heating of cells produced no significant chromosome aberrations. Moreover, some data indicate that electromagnetic fields may induce specific chromosomal aberrations (Baranski, 1971; Harte, 1975; George, 1978). Mutagenic effects of pulsed-modulated fields (8.6-9.0 GHz) were observed by Dutta *et al.* (1978) and some effects at 10 mW/cm^2 were not attributed to thermal mechanisms. Much effort has been directed at demonstrating the existence of carcinogenic, mutagenic and chromosome-damaging effects of low-level microwave irradiation with some success (Manikovska *et al.*, 1979; Yao, 1982; Balcer-Kubiczek and Harrison, 1985; Spitz and Johnson, 1985). Blackman *et al.* (1975) have done some carefully controlled experiments with suspensions of *E. coli* which were irradiated at 1.70 GHz in the near field or at 2.45 GHz in the far field. The only effect was an increase in the rate of cell growth in the irradiated bacteria in comparison with that for the sham-irradiated cells. The temperature was regulated to ±0.5°C. Szmigielski *et al.* (1975) found reversible functional disturbance of embryonic cells exposed to 3 GHz continuous wave fields during 30 min in the far field when no increase in temperature was observed. Chen and Lin (1978) exposed Chinese hamster (V-79) cells to 2450MHz CW at a power density 500 mW/cm^2 (SAR = 1059 W/kg). The authors reported a decrease in the growth rate and some morphological changes which were not due to temperature changes. Resonant-like non-thermal effects of millimeter microwave irradiation have also been obtained in yeasts (Grundler, 1985). Resonant microwave absorption of DNA molecules has been observed (Swicord, Davies, 1982; Sagripanti, Swicord, 1986). The exposure of purified plasmid DNA to microwave radiation at non-thermal levels in the frequency range from 2.00 to 8.70 GHz produces single- and double-strand breaks (Sagrinpanti *et al.*, 1987). Non-thermal effects of microwave radiation were reported in recent publications (Belyaev *et al.*, 1993; Pakhomov *et al.*, 1993 and others).

In spite of numerous studies aimed to prove the existence of non-thermal effects, a critical analysis of many publications related to this problem has made us

doubt the verisimilitude of these findings (Biological Effects..., 1986; Klauenberg *et al.*, 1995). Thus, one may conclude that (i) there is no solid generally accepted evidence for specific biological effects induced by non-ionising electromagnetic irradiation at cellular and molecular levels; (ii) the theory of non-thermal effects of microwave irradiation is yet undeveloped; (iii) further experimental and theoretical studies have to be conducted.

Specific thermal effects. The increasing practical utilisation of localised hyperthermia produced by microwaves for clinical therapy of malignant tumours makes topical the question as to whether the same biological effect would be expected when conventional heating is replaced by microwave-induced heating. It cannot be excluded that the thermal effects of microwaves might be different from those of classic hyperthermal treatments. Most studies on this subject point to the possibility of specific thermal effects in addition to the thermal effects of microwaves. Algae (*Chlamidomonas segnis*) were exposed to 2450 MHz field in log phase of growth in aqueous suspensions (Hamid and Badour, 1973). It was demonstrated that stimulation of photosynthesis and growth was greater then that induced by conventional heating. The interdependence of heat and microwave effects has been demonstrated in inactivation studies of *Bacillus subtilis* (Wayland *et al.*, 1977). Both bacteria *Escherichia coli* and bacteriophage T5 were more susceptible to inactivation by 1.07 GHz fields than by elevation of temperature alone (Moody *et al.*, 1979). Blevins *et al.* (1980) concluded that exposure to 2.45 GHz fields at power density of 5100 mW/cm^2 resulted in a significant increase in mutation rate relative to the effect of conventional heating. Chipley (1980) showed that microwave irradiation affected enzymatic activity of *Staphylococcus aureus* in a manner that could not be explained solely by thermal effects. Thus, the results of the cited papers show some biological responses to microwave irradiation that surpass the effect of conventional heating.

Thus, cell studies involving microwave irradiation can be subdivided in the following groups of observation: (i) demonstration of thermal biological effects induced by high-level electromagnetic exposure; (ii) illustration of specific effects of low-level microwave irradiation and (iii) evidence of specific thermal effects of microwave irradiation that surpass the effect of classical heating. Our own investigations presented below are devoted to the latter problem

Experimental device. An apparatus consisting of coaxially joined vessels for control (internal) and experimental (external) cell samples was constructed for studying specific thermal effects of microwave radiation (frequency, 7 GHz; SAR, 200 W/kg). Irradiation was performed using HEK polarised continuous waves. The vessel for the control (thermal heating) sample was made of radiopaque, heat-

conducting, metabolically inert, non-toxic material (stainless steel). The vessel for the experimental (microwave heating) sample was made of radiotransparent, metabolically inert, non-toxic material (plastic glass). Both vessels were placed into a thermoinsulating container, which was attached to a reversible mechanical rotator (5 total revolutions/min in one direction and 1/min in opposite direction). The external diameter of the experimental vessel was 17 mm, and that of the control vessel was 10 mm. The external wall of the control vessel served as the internal wall of the experimental vessel. The thickness of the irradiated cylinder of fluid was 3.5 mm. The total length of the system was 50 mm. The apparatus provides similar kinetics of heating of control and experimental samples owing to the fact that conventional heating was done by means of synchronous convection heating from the irradiated vessel.

Inactivation of pro- and eukaryotic cells. The repair proficient strains of prokaryotic (*Escherichia coli* B/r) and eukaryotic (*Saccharomyces cerevisiae*, diploid strain XS800) cells in stationary phase of growth were used in this investigation. The same cell suspensions of bacterial (10^8 cells/ml) and yeast (10^6 cells/ml) cells were placed into the arrangement vessels for experimental and control samples to provide identical heating rate for microwave and thermal treatments. After irradiation, the colony-forming ability was assessed by planting the cell suspensions on nutrient agar and counting macrocolonies after 24 h of incubation of bacterial cells at 37°C and after 3-5 days of yeast cell incubation at 30°C.

A lot of experiments was performed with *E. coli* B/r basing on the device described (Morozov *et al.*, 1995). Averaging these data, we calculated the dependence of the ratio of cell survival observed after conventional heating (S_H) to that obtained after microwave heating (S_M) on S_H (Fig. 1). One can see that the ratio S_H/S_M is increased with decreasing in cell survival S_H. Fig. 2 shows the correlation between yeast cell survival in control (usual heating) and experimental (microwave heating) samples. The broken line denotes the relationship between identical effects in microwave heating and thermal heating samples. It can be seen that the injurious action of microwave heat was greater than that of identical thermal heat alone both for prokaryotic and eukaryotic cells. In other words, microwave-heated cells were damaged more effectively than the cells exposed to thermal heating, this effectiveness being more expressed with cell survival decreasing. We may confirm therefore the existence of specific thermal electromagnetic effects differing from simple thermal action. It is worth noting that cell inactivation was not observed with simultaneous microwave exposure and cooling of samples. It follows that there is a relationship between radiospecific thermal and ordinary thermal effects. Fig. 3 illustrates the influence of exposure

duration by conventional heat (curve 1) and microwave heating (curve 2) on survival of *E. coli* B/r bacterial cells, and the influence of the incubation time at 37°C in isotonic (0.9% NaCl solution, curves 3, 4) and hypertonic (10% NaCl solution, curves 5, 6) solution on survival of cells exposed before inoculation by conventional heat (curves 3, 5) and microwaves (curves 4, 6). One can see from Fig. 3 that cell reparation from thermodamage during post-exposure time in isotonic media is independent of the fact whether it was induced by conventional (curve 3) or microwave (curve 4) heating. The same conclusion is true for additional damage produced by hypertonic solution.

Data pertaining to the dependence of bacterial *E. coli* B/r cell survival on sodium chloride concentration which was present in the cell suspension during exposure to conventional heating and microwaves are depicted in Fig. 4. As may be seen, various concentration of sodium chloride presented during exposure protected cells from thermal action. There is an optimal concentration of NaCl which maximised the protection effect from thermal damage induced by conventional heating. It of interest that the effectiveness of thermoprotection action was significantly decreased for microwave induced damage as compared with conventional heating. It means that microwaves induced more severe damage which can be modified to a lesser degree. This conclusion agrees with the above results (Figs.1, 2) showing that injurious action of microwave heating was greater than that of equivalent thermal heat alone.

It is a well-known hypothesis that a cell membrane may be a sensitive target for heat and microwave treatment. Therefore, it would be of interest to compare permeability of cell membranes after conventional and microwave heating. Fig. 5 exhibits the effect of these modalities to permeability of cell membranes to nucleotides estimated in our experiments by measurement of optical density at 260 nm of supernatant of *E. coli* B/r cells (Fig. 5, A) and Erlich ascites cells (Fig. 5, B) by a spectrophotometer (SPH-46 LOMO). One can see that increased permeability of cell membranes was observed after both microwave and conventional heating.

Here again, microwave heating induces more cell membrane damage than the equal thermal heating both for pro- and eukaryotic cells. It confirms our assumption about the existence of a specific thermal electromagnetic action of microwave irradiation of both pro- and eukaryotic cell organisms distinguished from the usual heat effects.

The influence of microwaves and conventional heat on dynamics of heating of samples of intact and inactivated bacteria *E. coli* B/r and various solutions of some basic molecular components of cell was also studied (Morozov *et al.*, 1996).

Some results are summarised in Fig. 6 and in Fig. 7. It is clear from these data that microwaves induce different dynamics of heating of all the samples investigated. On the contrary, thermal action induces identical dynamics of heating of all these samples except vegetable oil which was heated more intensively.

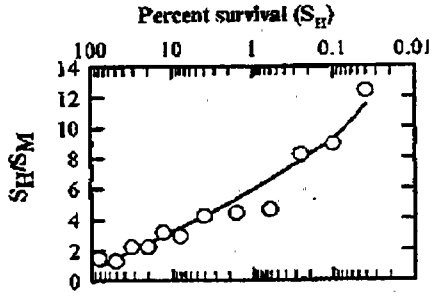

Fig. 1. The dependence of the ratio of cell survival observed after conventional heating to that obtained after microwave heating (S_H/S_M) on S_H for *Escherichia coli* B/r cells.

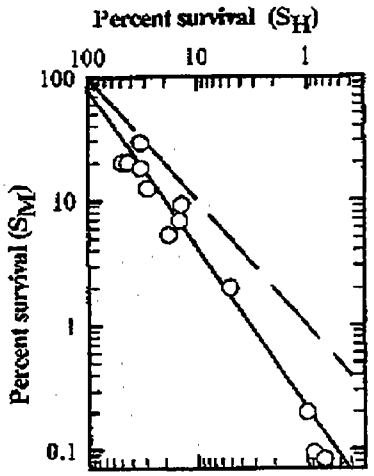

Fig. 2. The correlation between yeast cell survival in control-(thermal heating) and experimental (microwave heating) samples, and the regression line fitted by least squares method.

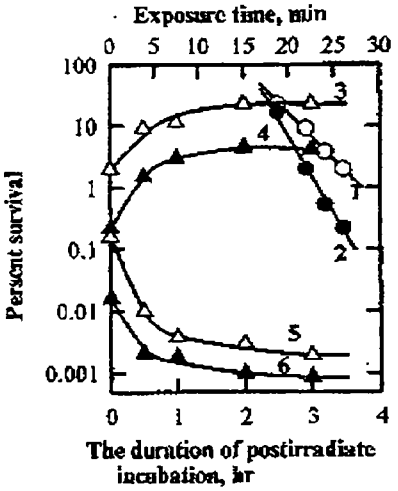

Fig. 3. The influence of exposure duration to conventional heat (curve 1) and microwave heating (curve 2) on survival of *E.coli* B/r bacteria, and the influence of the incubation time at 37°C in isotonic (0.9% NaCl, curve 3, 4) and hypertonic (10% NaCl, curves 5, 6) solutions on survival of cells exposed before inculation by conventional heat (curve 3, 5) and microwaves (curve 4, 6).

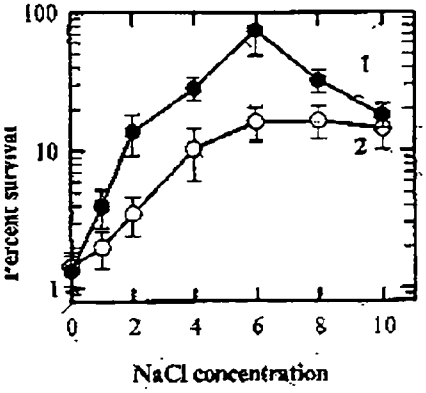

Fig. 4. The dependence of bacteria *E. coli* B/r cell survival (%) on NaCl concentration which was presented in cell suspension during exposure to conventional heat (curve 1) and microwaves (curve 2).

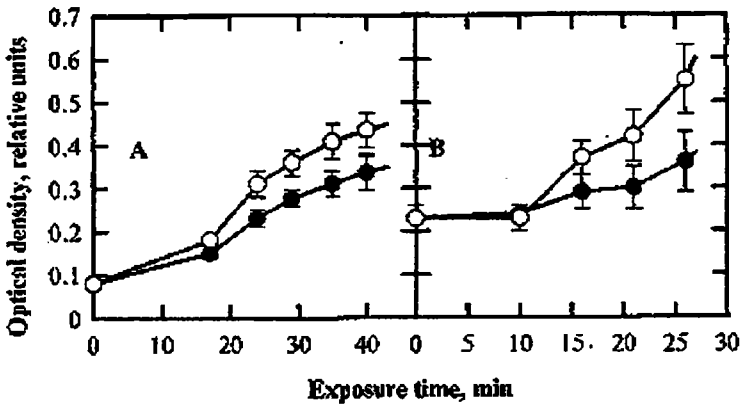

Fig. 5. The dependence of optical density (relative units) of supernatants in control (usual heating, closed circles) and experimental (microwave heating, open circles) cell samples for bacterial *E. coli* B/r cells (A) and Erlich ascites cells (B).

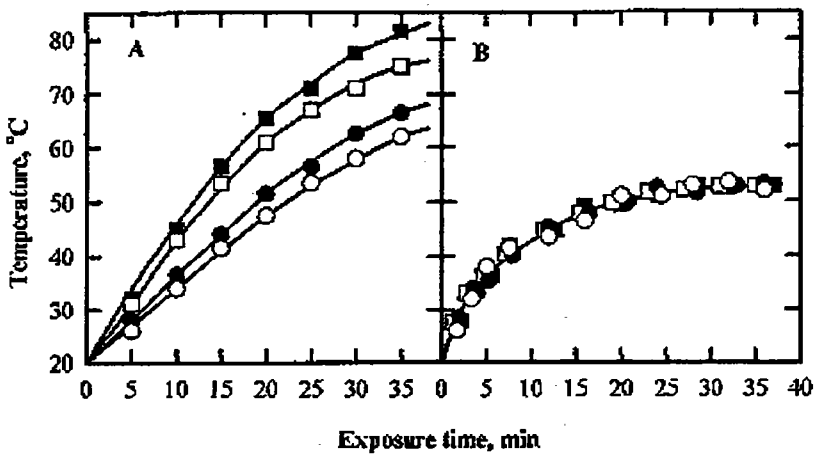

Fig. 6. Dynamics of heating in the dependence of exposure duration for microwave (A) and conventional (B) heating of various samples: ■ - saline suspension of intact bacterial *E. coli B/r* cells; □ - saline suspension of previously inactivated bacterial *E. coli B/r* cells; ● - solution of some basic molecular components of cell; ○ - saline solution only.

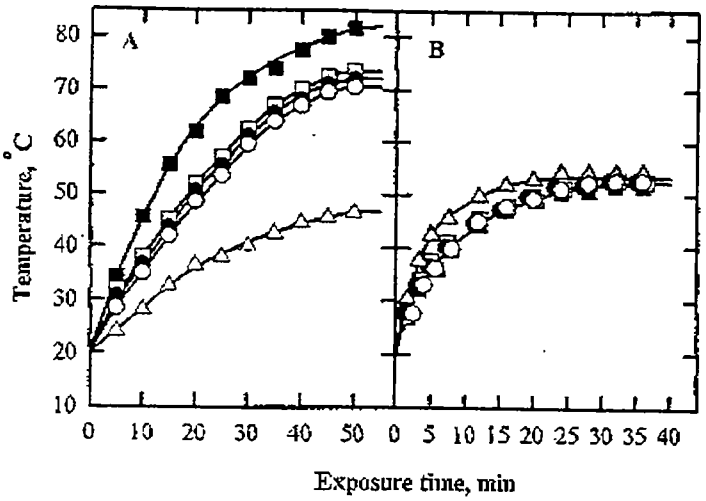

Fig. 7. Dynamics of heating in the dependence of exposure duration for microwave (A) and conventional (B) heating of various samples: ■ - saline suspension of intact bacterial *E. coli B/r* cells; □ - peptone solution; ● - DNA solution; ○ - sucrose solution; △ - vegetable oil.

Thus, the peculiar feature of biological effects of electromagnetic non-ionising radiation at high power density and usual thermal heating of cell suspensions and some basic components of cell shows that microwave irradiation can produce specific thermal effects which are different from the effects produced by simple conventional heating.

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CHRONIC MICROWAVE IRRADIATION INFLUENCE ON COMPONENTS OF AGROECOSYSTEMS.

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Dear colleagues, in our report we would like to present the findings of our experiments on chronic microwave irradiation of agroecosystems.

Material and methods

Irradiation was conducted in field conditions by means of microwave installations E-3 and E-10, working on wavelengths of 3 and 10 cm. The microwave installations are pulse and magnetron generators of 150 kW and 700 W pulse power respectively.

The power levels of microwave radiation were measured by a Ya2M-20 device.

The experiments on irradiation of insects were conducted in a microwave radiation field with λ=3 cm and ППЭ $\approx$ 150-200 mW/cm^2 and exposition from 1 up to 25 minutes.

In a two-year field experiment, irradiation of growing plants was conducted during daylight hours of two summer months (June - July) by means of a microwave installation with wavelengths of 3 and 10 cm and various levels of ППЭ - from 0,15 up to 1,3 at λ=3 cm and from 4,8 up to 12,8 mW/cm^2 at λ=10 cm. The researches were conducted on regionalized (for Kaluga oblast) grades: wheat - grade Rodina, potatoes - grade Detskoselsky. The density of energy flow, depending on the distance from the radiation source was: at the wavelength of 3 cm - from 0,15 up to 1,3 mW/cm^2, and at 10 cm - from 4,8 up to 12,8 mW/cm^2.

Regular observations were conducted over the growth and development of the plants during the entire vegetation period. Development phases of both irradiated and not irradiated plants and their height were controlled. Besides, the wheat was measured for the length between nodes, area of leaves, ear size, amount and weight of grain in the ear, mass of straw, while the potatoes - for the weight and marketability of tubers.

Alongside with evaluation of biological action of microwave exposure of agricultural plants, a study of the effects of microwave radiation on soil nitrogen fixation microorganisms and on some phytopathogenic microflora was made.

Outcomes of researches and discussion

In table 1 the behavioral responses of insects are presented. The table shows, that the densities of microwave - radiation power flow, used in the experiment, were sufficient to cause the death of all the investigated insects "under the rays".

It was found that irradiation of agricultural plants (potatoes, wheat) with similar power performances and with the same exposition does not result in their lesion or losses of the crop. Thus, certain kinds of insects are considerably less resistant to thermal microwave radiation in comparison with agricultural plants. Contrast resistance of insects and plants to thermal microwave radiation can make it possible to use this property in for fighting the vermin.

The chronic microwave irradiation with the above parameters did not substantially influence the development phenophases of either the wheat or the potatoes. The observations of the plants' growth the following year after their irradiation did not reveal any changes either.

At the same time, the reduction of grain weight in the ear was established. Exposure to 3-cm wavelength and PD of 0,25 up to 1,3 mW/cm^2 resulted in the reduction of weight of grain by 26-38%, while exposure to and 10-cm wavelength and PD 6,7 up to 12,8 mW/cm^2 produced changes within the same limits. The weight reduction of grain is probably connected with the observed reduction of the leaf area of the plants. The following year after the irradiation (M1) no such deviations were noted and no changes in the growth and development of the wheat was detected.

Unlike the wheat, the potatoes were to a greater extent affected by chronic microwave irradiation. It was established, that the chronic microwave irradiation (3 and 10 cm) had caused inhibition of the development of the plants.

As seen form the data in Table 2, the exposure-induced inhibition resulted in the reduction of productivity and quality of the potatoes. From table 2 it is seen, that, depending on PFD, irradiation at 3 cm wavelength has caused a reduction of tuber weight by 1.2-2.2 times, while that at 10 cm - by 1.2-1.4 times. Accordingly, the tuber marketability was reduced too.

Table 1. Behavioral responses of insects

Kind of insect	# of variant	Beginning of motor activity after starting the generator, sec	Death of first subject, sec	Onset of slow mobility, min, s	% of deaths on 4th minute	% of deaths under rays	% of deaths after 24 hours
Bugs	1	10	35	2'	90	90	90
Palomena	2	15	45	1'50"	90	90	90
Prasina	3	10	40	2'	90	100	-
	4	15	60	1'20"	70	70	
	x_{av} M±m	12,5±1,2	45± 3,6	1'47"±10"	85±4,8	87,5±7,2	83±4,8
Flies	1	45	285	6'	10	30	90
Musca	2	60	180	0'	10	30	80
Domestica	3	80	165	9'	10	30	60
	x_{av} M±m	62±11,9	210± 41	15'±3'	10	30	77±10
Beetles	1	25	240	12'	10	80	100
Leptinotarsa	2	30	335	9'	30	90	90
Desemlineata	3	35	240	8'	20	100	-
	M±m	30± 03	272±33	9'±2'	20±7	90±7	95±3
Ants	1	10	80	7'	60	90	100
Formica	2	12	160	9'	40	80	90
Rufa	3	13	180	11'	20	70	100
	4	10	100	12'	20	70	90
	X_{av} M ±m	11 3±0 7	130±24	10'±1'	35±10	77±5	95±3
Cockroaches	1	15	25	80"	70	70	70
Blattella germanica	2	20	40	70"	70	70	80
	3	15	45	90"	90	100	-
	M±m	16,6±2	36±7	80"±7"	76±7	80±10	75±3

The studies conducted on the following generation (M1) did not reveal essential differences in the growth and development of potatoes.

Along with the study of the action and aftereffects of chronic microwave irradiation on the growth and development of wheat and potatoes, we conducted a simultaneous study of their resistance to fungus diseases. The reason for this was that the violation of the traditional interrelations in the system plant-host-pathogen can entail changes of the harmfulness of the disease.

The observations conducted during the entire vegetation period established that the wheat was affected by peronosporos and brown rust, and potatoes - by phytophtorosis.

Table 2
Effects and aftereffects of chronic microwave irradiation on a crop of potatoes

Power density, mW/cm2	Generation M		Generation M_1	
	Gross weight of tubers from a plant, g	Weight of marketable tubers from a plant, g	Gross weight of tubers from a plant, g	Weight of marketable tubers from a plant, g
0	615,0±22,9	512,9±21,6	387,6±14,2	277,6±15,3
Wavelength λ=3 cm				
1,3	282,3±30,9*	211,4±30,9*	331,6±25,7	238,6±28,7
0,95	434,5±35,8*	350,2±38,6*	436,8±27,3	339,7±30,4
0,31	470,7±71,8*	364,7±60,8*	407,5±24,6	325,1±27,2
0,25	510,1±32,6*	435,6±33,5*	379,3±17,8	240,3±20,1
0,15	618,0±42,2	511,0±38,2	403,5±17,1	318,9±19,1
Wavelength λ=10 cm				
12,8	441,4±25,0*	335,5±21,8*	283,7±14,2	190,0±15,7
10,9	499,3±25,9*	400,7±23,5*	298,8±19,3	190,2±20,9
10,5	516,9±25,1*	424,4±23,4*	323,3±26,7	241,6±27,3
6,7	554,1±24,1	449,9±22,6*	321,1±19,5	241,4±21,7
4,8	587,3±28,4	502,3±25,3	346,7±21,4	248,0±24,0

* - The distinction is authentic at the level of 0.95

Chronic irradiation of the wheat did not influence its development, but the amount of the plants affected by brown rust increased.

Unlike the wheat, where the diseases appeared simultaneously both on the exposed and unexposed plants, peronosporos on the potatoes was found on the unexposed plants during their flowering, while on the irradiated plants it appeared only 6-7 days thereafter. No differences were detected between the time of the appearance of the diseases as a function of the exposure wavelength or exposure intensity.

The observations established a tendency towards a reduction of phytophtorosis incidence in the potatoes. The degree of reduction depended both on the wavelength and on PFD.

Thus, the microwave irradiation during vegetation caused a reduction in phytophthorosis of potatoes, did not practically affect the amount of wheat peronosporos, and caused an increase in wheat brown rust incidence.

Our aim included a study of the biological activity of soil and the status of the complex of soil microorganisms, as the most important component agrobiocenosis under the conditions of chronic irradiation of soil by microwave-range EM rays. The biological activity of soil is characterized by intensity of

various physiological processes, of which the most important is the nitrogen fixation ability of soils.

The initial data describing the conditions of the experiment, are presented in table 3.

Calculation of an integrated parameter of nitrogen fixation A according to the amount of N_2 fixed during the entire period under study (disregarding the nitrogen dissimilation processes), has shown, that the nitrogen fixation level of the unexposed soil considerably exceeds the nitrogen fixation levels of soil in all the researched cases with the irradiated soil (figure 1,2).

Table 3
Initial soil microwave irradiation performances.

Variants of experiment	Distance from source, i	PFD, mW/cm^2	
		λ_1=3 cm	Λ_2=10 cm
1	5	1,020	13,0
2	10	0,600	13,0
3	15	0,280	9,
4	20	0,072	7,2
5	25	0,024	2,3
C*	-	-	-

* - as control, we used the ground in the investigation area, shielded from the source of microwave radiation.

A reduction of the level can occur due to the reduced activity of the nitrogenase enzyme, responsible for the fixation of atmospheric nitrogen, or to the reduced number of nitrogen fixation microorganisms. To answer this question, further studies are necessary.

It was also established that chronic microwave exposure of soils results in the disturbance of the structure of the complex of soil microorganisms, when the ratio of certain groups of microorganisms necessary for the fulfillment of physiological functions in the soil is changed.

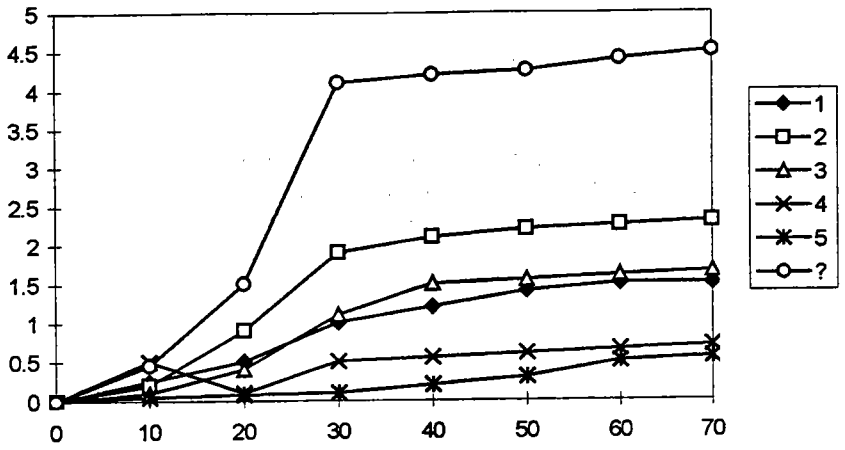

Fig.1. **Dynamics of integrated nitrogen fixation at irradiation of the experimental areas by I-3 installation.**

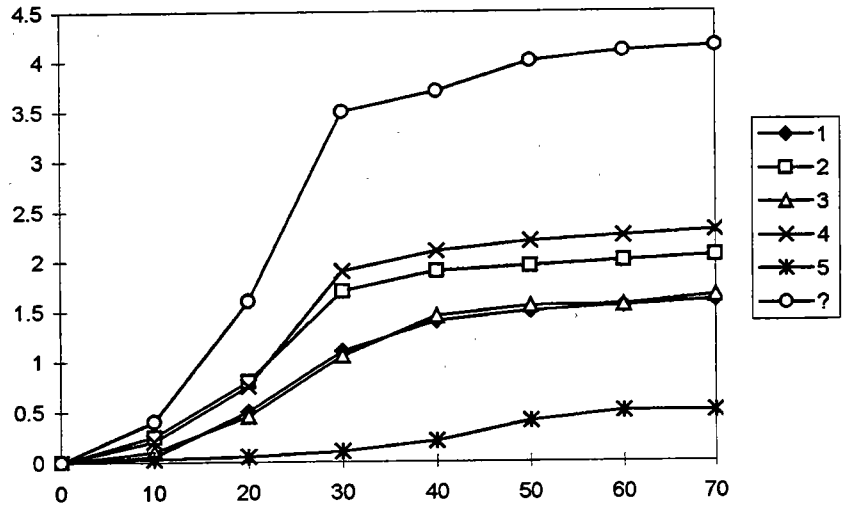

Fig.2. **Dynamics of integrated nitrogen fixation at irradiation of the experimental areas by I-10 installation.**

Some results of our researches were published in the works shown below. We present biological effects of UHF exposure of animals in a separate report. Unfortunately, the difficult economic situation of the country has not allowed us to continue our experimental researches on chronic microwave exposures in field conditions, though Obninsk still possesses the technical and personnel possibilities for conducting such work.

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ESTIMATION OF THE BIOLOGICAL EFFECT OF COMBINED (RF, UV, γ) EM RADIATION ON FARM ANIMALS (SHEEP)

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The global excess of the natural EMR background in the radiofrequency range, the local excess in the range of ionising radiation (as a consequence of the Chernobyl NPP accident) and a potential local enhancement of the short-wave UV-radiation due to the ozone layer depletion gave rise to the conditions favourable for different combinations of ionising and non-ionising radiation affecting the biosphere. This was a prerequisite for addressing the topical problem of experimental study of isolated and combined EMR effects on farm animals as one of the components of agroecosystems.

Biological effects of electromagnetic radiation have been much investigated [1], however, most of the data are quite contradictory [1-5]. A combined action of radiation of different ranges has been hardly studied at all; no biological or especially ecological assessment of the consequences of such an exposure has been made either.

The aim of the present paper is to study both combined and isolated effects of RF, UV-B and γ-ranges on the functional state of some systems of the body of sheep.

Material and methods

The experimental studies of the combined EMR effect were conducted on 35 sheep of the Precos breed with a live weight of 40 ±1,8 kg divided by the analogue principle into 6 groups:

Group 1. In a specially equipped chamber measuring 1,5 by 1,5 m enhanced levels of the UV-B radiation were set up using the LER-40 type erythema inducing luminescent lamps the spectral composition of which within the 280-320 nm range is close to that of the solar radiation. The irradiance in the exposure zone measured by the integral radiometer UVX-31 (USA) was 5,5 W/m^2. The group irradiation was performed for 1 hour daily during 15 days.

Group 2. Individual RF-treatment of sheep took place in an echo-free chamber using the G4-8 generator operating in the continuous mode at 2

GHz. The fluence rate at the level of animal head was 0,5 mW/cm^2. The EMR flux was directed cranio-caudally downwards at an angle of 45^0. The animals were treated daily for 1 hour during 15 days. The EMR level was monitored with the P3-9 device. The uniformity of the EMR distribution in the echo-free chamber did not exceed 10%.

Group 3. Single γ-irradiation on the "Gamma-Panorama" device with ^{137}Cs source at a dose of 3,17 Gy and dose rate of 0,244 cGy s^{-1} (LD_{50}).

Group 4. Combined UV-B+RF treatment. The irradiation parameters are identical to those in groups 1 and 2.

Group 5. Combined γ+UV-B treatment. Immediately after γ-irradiation the sheep were UV-B treated according to the scheme for group 1.

Group 6. Control.

During the experiment clinico-physiological examinations (live weight, body temperature, general well-being) were made by the conventional methods of veterinary medicine. The amounts of leukocytes, erythrocytes, haemoglobin and haematocrit were estimated by the agreed-upon methods. The haemostatic indices were measured with the type A-334 coagulograph, taking into account the starting and completion time of blood coagulation (T_1 and T_2), as well as the overall coagulation time (T) expressed in seconds. The electrocardiography was made by the M.P.Roshchevsky method and evaluated by the following parameters: value of P, QRST (mB) waves, interval duration (R-R), (Q-T), (T-P) in second. Besides, a systolic index SI=(Q-T)/(R-R) x100% and systolic-diastolic index equal to the ratio of systola (Q-T) and diastola (T-P) duration SD=(Q-T)/(T-P) x100% were estimated. Cellular populations of thrombocytes and thrombocytic-lymphocytic suspension of sheep blood cells were isolated by centrifugation at the verographin density gradient with a specific density of 1,077 g/cm^3 in our modification of the previously described methods [9-11,12]. The intensity of the UV fluorescence at an excitation wavelength of 290 nm and fluorescence wavelength of 355 nm, as well as light scattering of blood cells suspensions at an angle of 90^0 were registered on the Hitachi spectrofluorimeter, Model 650-60 (Japan).

The experimental results were statistically analysed by the Student test.

Results and discussion

Clinical studies of sheep in dynamics have demonstrated that live weight, rectal temperature and general well-being of the control and experimental groups did not differ significantly. Only animals that received γ-irradiation at a semilethal dose showed an inhibited state, increased respiration and pulse rate, decrease in live weight, as well as temperature response and leukopoenia (Fig.1) typical for acute radiation disease, which was supported by the post mortem examination of the two dead animals.

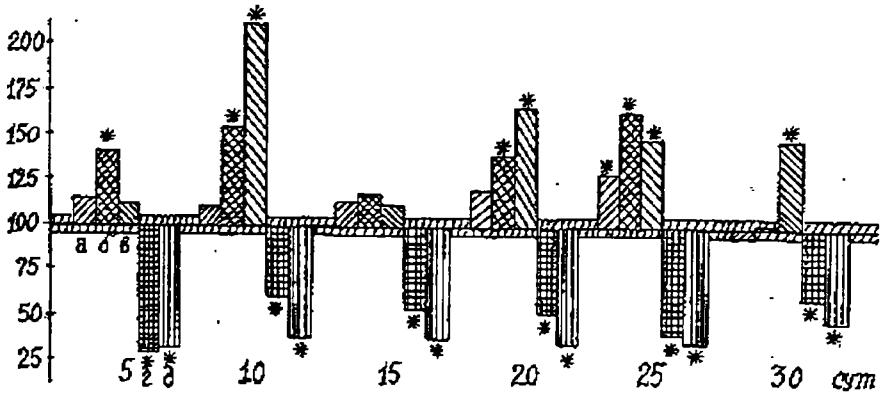

Fig.1. Changes in the number of leukocytes in sheep blood for different treatments: a - UV, b - UV+RF, c – RF, d - γ+UV, e - γ. The abscissa is the time of study, days; the ordinate is per cent compared to control. * - significant difference from parallel control ($p<0,05$).

The pattern of variations in the haematological parameters in the experimental dynamics manifested itself as dependent on the type of the physical factor. Thus, isolated chronic UV-B irradiation caused some decrease in the number of erythrocytes (by 2,2-13,7%) and haemoglobin (by 0,1-17,9%) in sheep blood between days 5 and 25 and as can be seen from Fig.1 a quite significant growth in the number of leukocytes (by 9,8-29,4%). RF-irradiation had an insignificant influence on the quantitative parameters of erythrocytes, reliably increased the haemoglobin level from day 25 through day 30 (by 13,6-40,8%) and increased the number of leukocytes at all times of the study (by 11,2-112%). The content of erythrocytes and haemoglobin in the blood of the animals treated by a combined (UV-B+RF) radiation remained within the norm, whereas the level of leukocytes in the sheep blood (Fig.1) was intermediate - between that for isolated

exposure on days 10, 20 and 30 and exceeded it on days 5, 15 and 25. A sublethal γ-irradiation dose resulted in a reliable reduction of the number of leukocytes in the blood (Fig.1) and insignificantly influenced the quantities of erythrocytes and haemoglobin.

A combined (γ+UV-B) treatment did not alter significantly the amount of haemoglobin and erythrocytes compared to the isolated γ-irradiation, whereas the content of leukocytes significantly increased on days 10-30.

The results of the haematological examinations make it possible to conclude that in combined treatments of animals the UV-B radiation in both variants acts as a modifier of the biological effect (days 10-30), normalising an increased, due to UV-B-irradiation, level of leukocytes and restraining an abrupt decrease in the level of leukocytes in sheep blood induced by isolated γ-irradiation (days 10-30).

According to the results of light scattering at 90^0, the UV-B irradiation as early as on day 1 causes a 1.3-fold reduction in this parameter. Decreasing insignificantly on day 3, it remains above the control values during the entire exposure period and returns to normal after the completion of the exposure. On RF exposure, the values for light scattering of cells at an angle of 90^0 exceed the control level by 35-36% during the treatment period remaining above the norm for 25 days after completing the exposure. On a combined (UV+RF) exposure, the parameter showed an increase on day 15, an insignificant increase was observed after the treatment termination. The parameter of light scattering of cells at an angle of 90^0 provides information on the morphology and form of the plasma membranes of cells [13]. Since the above types of irradiation did not significantly alter the morphological composition of blood cells, one plausible explanation of the increased values for light scattering of cells might be the alteration of the cellular surface form of thrombocytes or lymphocytes caused by structural-functional changes in the cytoplasmic membranes of cells.

For a more precise definition, the UV fluorescence (UVF) of the same cellular suspension was studied, which is an important way for analysing the state of the protein phase of plasmatic membranes [13]. The UVF values for the suspension of sheep blood cells are presented in Table 2.

As is seen from Table 2, as early as one day after UV-irradiation of the animals the UVF intensity of cells increased by 50%. This parameter, as well as the value of light scattering at 90^0, remained above the norm during entire period of exposure and only decreased following the completion of irradiation. A combined

(UV+RF) treatment resulted in an increase in this parameter on day 15 and its approaching the control values on succeeding days.

Table 1
Values for light scattering at 90^0 of sheep blood cells at different times for UV, RF and combined animal treatments

Time of study, days	Treatment		
	UV	RF	UV+RF
Control	694,44±12,88	694,44±12,88	694,44±12,88
1	904,07±27,87*	-	655,12±12,62
3	809,15±51,92	-	670,58±26,44
7	-	933,20±70,57*	630,49±13,35*
10	826,28±19,54*	-	-
15	847,16±35,30*	944,20±13,94*	893,54±38,65*
20	784,92±22,64*	823,74±33,44*	781,77±26,03*
30	737,63±47,56*	-	760,60±28,02*
40	776,24±45,40*	849,40±42,79*	-

*- $p < 0,05$

On RF exposure, increased values of the UVF intensity of cells were registered at all observation times.

Since the UVF intensity of cells is determined by the protein structures of cytoplasmic membranes associated with the lipid hydrophobic fraction, during isolated UV and combined (UV+RF) irradiation within the exposure period, as well as during and after UHF exposure at all the irradiation modes under study there occur structural rearrangements of the protein phase of cellular cytoplasmic membranes governing the functional state of some vitally important enzymatic systems.

EMR in the ranges under study, in both isolated and combined modes cause certain changes in the haemostasis system of sheep (Fig.2). Thus, γ-radiation considerably prolongs the blood coagulation time in sheep, starting from day 15 to day 30 (by 18-103% compared to the control). This effect results from an abrupt increase in the termination time of blood coagulation. Other physical factors (isolated UV-B and RF irradiation) somewhat shorten the coagulation time from day 5 through day 25. Significant differences are reported for days 5 and 25.

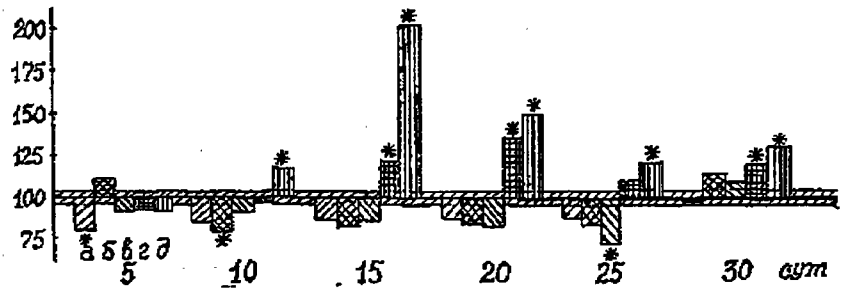

Fig.2. The length of the coagulation period (T) in sheep for different treatments. The symbols are as in Fig.1.

Table 2
UVF intensity of sheep blood cells exposed to UV, RFand combined irradiation at different times of study

Time of study, days	Treatment		
	UV	RF	UV+RF
Control	0,188±0,016	0,188±0,016	0,188±0,016
1	0,289±0,019*	-	0,197±0,013
3	0,233±0,008	-	0,198±0,012
7	-	0,271±0,022*	0,161±0,010*
10	0,232±0,013*	-	-
15	0,236±0,017*	0,255±0,007*	0,234±0,040*
20	0,205±0,014*	0,251±0,016*	0,205±0,012*
30	0,193±0,011*	-	-
40	0,202±0,004*	0,193±0,038*	0,193±0,014*

*- $p < 0,05$

A combined UV-B+RF treatment causes some changes in the haemostasis system of sheep characterised both as synergetic (days 10, 15, 30) and having a reverse tendency (day 5).

During a combined UV-B+γ irradiation, the length of the coagulation period in the sheep on days 10-30 approaches the norm (Fig.2). Thus, variations in the haemostasis system of the sheep induced by γ-radiation are rather well levelled out by a combined treatment due to the modifying effect of the UV-B radiation.

The above treatments result in certain changes in the cardioactivity of the animals (Fig.3 A, B).

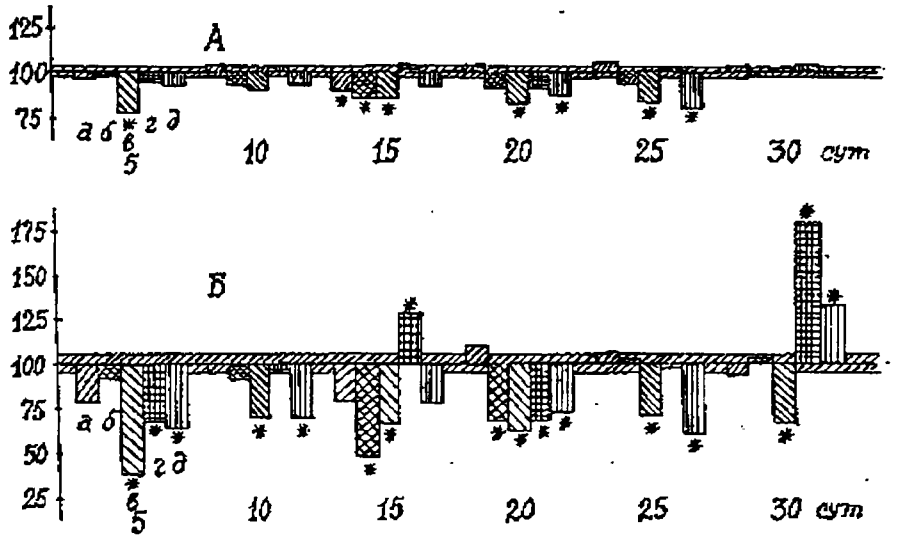

Fig.3. Variations in the systolic (SI, A) and systolic-diastolic (SD, B) ECG indices of sheep for different treatments. The symbols are as in Fig.1.

The ECG analysis of the sheep subjected to chronic (15 days) UV-B-irradiation at suberythematic doses has shown that the heart rate, systole duration and systolic index remain within the physiological norm throughout the entire study period. Some functional changes were noted in the diastole duration (T-P), systolic-diastolic index (SD), value of V-wave which persisted after exposure (for 20-30 days). Besides, the animals developed persistent arrhythmia and conjunctivitis in 50-60% of exposed sheep. These signs are unfavourable in terms of prediction.

Some functional changes were found in the ECG values of the sheep exposed to chronic non-thermal RF radiation. However, most of these were quite opposite to the UV induced variations (days 10, 20 and 25). A decreased heart rate was registered which was functionally connected with the increase in the R-R interval. In this case the passive interval (T-P) became longer from day 1 through day 30 and, consequently, the SD index decreased at this time with some increase in the systole period (Q-T). These positive shifts are directly connected with the

intensity of metabolic processes in myocardia and this manifests itself in the T-wave increase.

Pathologic ECG changes were reported only in the sheep exposed to acute γ-radiation which died later on: decrease in the diastolic and increase in systolic-diastolic index, arrhythmia. Other animals showed changes of adaptive character.

During a combined (γ+UV-B) irradiation the effect of γ-radiation which is a dominant factor is modified by the UV-radiation. This appeared as an increased number of blood leukocytes compared to the isolated γ-irradiation effect. In addition, the chronic UV irradiation that follows the acute γ-irradiation stimulates the intensity of metabolic processes in myocardia and normalises the systolic index.

So, during a combined exposure the biological effect is primarily caused by a leading factor, such as γ- and RF-radiation.

To summarise it can be noted that the study of biological effects of the UV-B, RF and γ-radiation and their combinations has allowed us to estimate the body sensitivity to these factors and its adaptive potentials. The UV-B, RF and γ-radiation caused functional changes in the sheep body systems under study. The revealed shifts are most likely an adaptive response to irradiation. However, their significance for the body is different: some of these (leukopoenia during γ-irradiation) have an unfavourable forecast; others (ECG, haematological values) are of adaptive nature; still others (arrhythmia, conjunctivitis, live weight loss) can be unfavourable in terms of forecast and should be considered as pre-pathologic. The effects of combined irradiation of the EMR ranges studied depend on the dominant factor and can be modified by the radiation energy whose characteristics differ from those of the dominant factor, due most likely to different mechanisms of action.

An analysis of our own [6-8] and literature [1-5] data suggests that an assessment of the ecological consequences of combined EMR on components of natural and agricultural ecosystems is only possible if a complex of technogenic factors are considered, such as prolonged action of EMP from radar stations and other RF sources, increased UV-B levels due to the ozone layer depletion, local radioactive fallout and others. The methodology for estimating a combined effect of different EMR ranges and other factors includes the study of the sensitivity series of the major elements of agroecosystems (farm animals, plants, insects, soil microbiocenosis) aimed at identifying an ecologically significant test-object in terms of productivity and survival, as well as the most sensitive test-systems based

on the morphophysiological, cytogenetic, electrophysical and biophysical indicators. This will allow both to develop criteria for estimating negative EMR effects and to calculate maximum permissible levels of the EMR of different ranges.

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DEPENDENCE OF THE HUMAN ELECTROENCEPHALOGRAM (EEG) SPATIAL SYNCHRONISATION ON THE GEOMAGNETIC AND SOLAR ACTIVITY ON THE DAY OF THE EXPERIMENT

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The aim of this work is to investigate a possible relation between the geophysics parameters and the human EEG. The problem of magnetic sensitivity of the body is complicated by the fact that the effects observed depend heavily on the experiment conditions. This fact will eventually produce high instability of the results and their low reproducibility.

The investigation was carried out from July to December 1992. Each of the subjects participated in the experiment only once. A monopolar electroencephalogram (EEG) from 12 points of the cortex (F3,F4, C3,C4, P3,P4, O1,O2, F7,F8, T5,T6) from 26 subjects (13 males and 13 females) was recorded under different experimental conditions (problem solving, rest). The spontaneous EEG synchronisation parameter was calculated for every site pairs by computation of Pearson's correlation coefficient between two EEG processes. The indices of synchronisation for all possible pairs of sites were compared with the following geophysical parameters: 1) the values of geomagnetic Ap-index on the day of the experiment, on the day before the experiment and on the next day; 2) the values of solar activity (number of sunspots) on the day of the experiment and 1, 2, 3, 4 days before the experiment date.

The EEG synchronisation indicators revealed a reliable positive correlation with Ap-index for a number of pairs of sites. The strongest relationship was observed in 8 pairs of sites presented in fig.1A. The Pearson's rank correlation with geomagnetic Ap-index ranges from 0.41 (C4-P3, $p<0.05$) to 0.64 (F3-C3, $p<0.01$). It is 0.58 ($p<0.01$) on the average for this block of sites (see also fig.2A). Fig.3A demonstrates the correlation between certain EEG-synchronisation indices and the geomagnetic activity (Ap) measured on the day of the experiment, on the day before the experiment and on the next day. As indicated in the picture, a reliable correlation occurs only on the day of the experiment whereas the correlation is lacking on the nearest days.

In our previous article, based on the same data, stable distinctions between males and females by level of global EEG-synchronisation were revealed. Sex differences as well as a correlation to Ap were observed for all cortical areas with somewhat greater prominence in anterior sites [3]. On this basis we can assume

that the character of the distinctions between EEG-synchronisation values measured in 'magnetic' and 'quiescent' days are similar to the sex differences in this parameter. This assumption was confirmed by the method of multifactor analysis of variations (ANOVA). ANOVA showed that both the sex factor and Ap-index affect the EEG-synchronisation ($p=0.026$; $p=0.008$ respectively). It also revealed a reliable interaction between these factors. In this connection we compared our data for males and females separately. The positive correlation between Ap-index and EEG-synchronisation was confirmed for females. The males showed similar correlation but it was considerably less so.

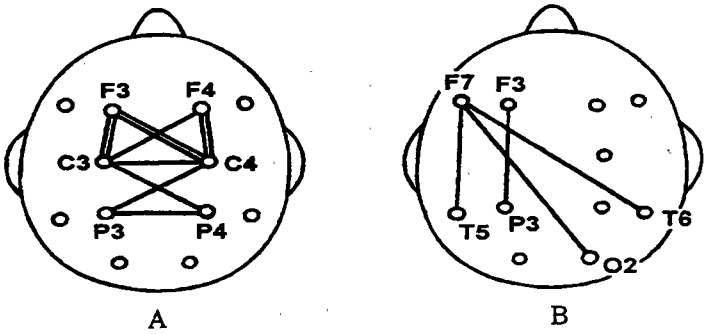

Fig.1. The indicators of EEG synchronisation between the pairs of cortical sites which are connected by straight lines revealed strong statistic relations to geomagnetic and solar activity. A – positive correlations to geomagnetic Ap-index; B – negative correlations to the number of sunspots. Single lines correspond to the correlation with 95% level of significance; double lines correspond to 99% level of significance.

Hence it is believed that the spontaneous EEG-synchronisation depends on the current level of the geomagnetic activity. The indirect evidence for the presence of this correlation is the dependence of the correlation between EEG and Ap-index from the day when Ap-index is measured (see temporal course of the correlation values in fig.3A).

In parallel with the Ap-index we also detected a negative correlation between EEG-synchronisation and solar activity (number of sunspots). It must be emphasised that the geomagnetic and solar activity indexes were not related statistically to each other. The dependence of EEG-synchronisation on solar

activity was considerably less than that on geomagnetic activity. The correlations were weaker and were observed for a smaller number of EEG sites. The site pairs F3-P3, F7-T5, F7-O2, F7-T6 revealed the closest relationships with the number of sunspots (fig.1B, fig.2B). The significant correlations add up to 66% from overall number of site pairs. Of all significant correlations only one pair refers to the right hemisphere, others are either in the left hemisphere or interhemispheric. Considering the fact that the dependence on solar activity is shown by the left hemisphere (i.e., it is more local in character) and has the opposite (negative) sign it may be suggested that here we are confronted by an EEG factor other than the magnetic sensitivity factor described above.

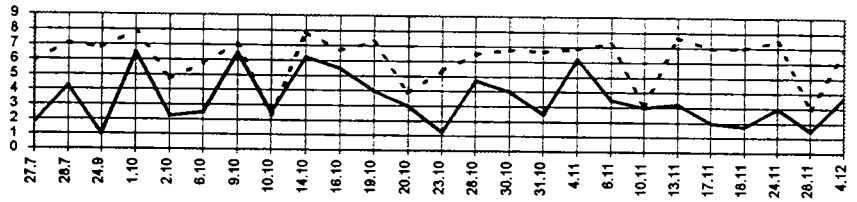

Fig.2A. The solid line corresponds to geomagnetic activity (Ap-index) on the days of experiments. The dotted line corresponds to average values of EEG-synchronization.

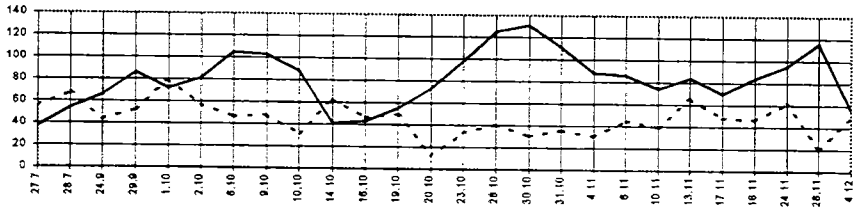

Fig.2B. The solid line corresponds to the number of sunspots two days before the experiment. The dotted line corresponds to average values of EEG-synchronisation on the same dates.

Thus, the structure of the «magnetosensitive» links (fig.1A) is highly similar to the structure of the links, which depend on the sex factor [3]. This fact suggests that the common physiological mechanisms are at the basis of this similarity. In order to clarify these mechanisms it is necessary to take as the point of departure the problem of sex dimorphism in brain activity organisation.

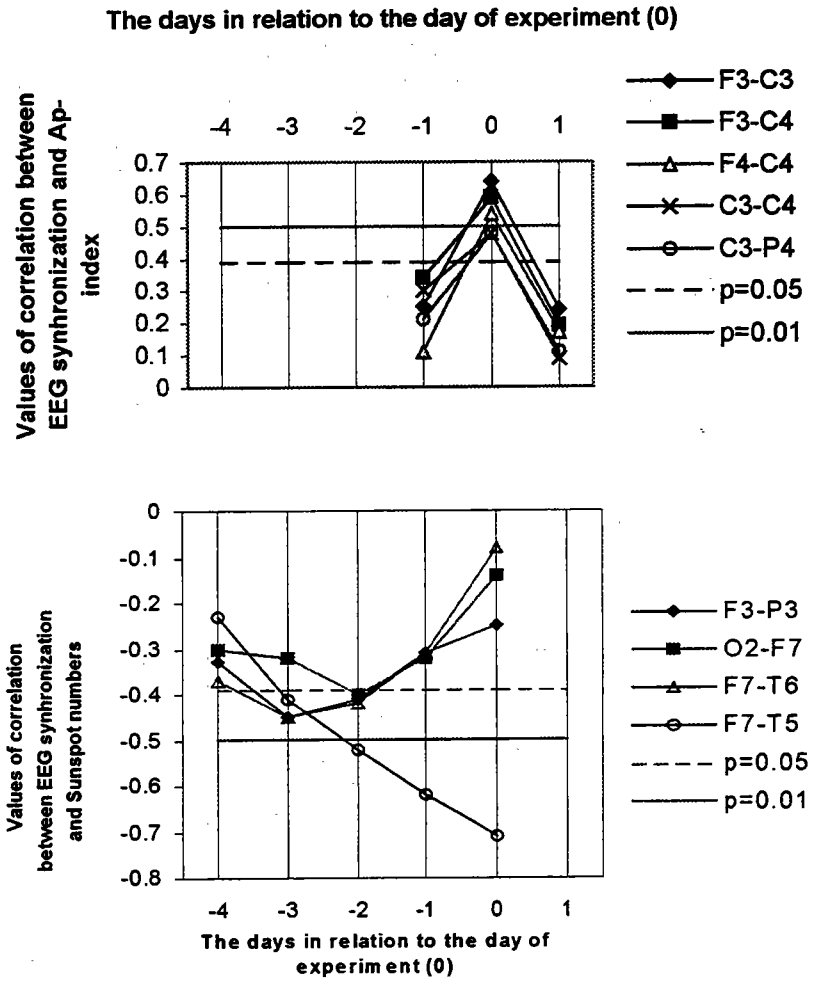

Fig.3. Correlations between Ap-index (upper graphic), Number of sunspots (lower graphic) and EEG-synchronisation as a function of the day in relation to the day of the experiment.

It is known from the physiological literature, that there are sex differences in the visceral parameters derived from dissimilar hormonal status and neurochemical factors of males and females. Females have a more active opiate brain system [1]. Because of this they are less sensitive to pain. Under stress reaction the vasopressin, ACTH and oxytozin ejection is more powerful in females compared to males. In females the feature of visceral stress reaction lies in the fact that they have a lower sympathetic tonus during anxiety or hypercompensation stage in comparison to males. Hence females are characterised by a smaller increase in arterial tension, pulse rate and respiration rate. As to the greater part of the above-listed parameters, we found their dependence on geomagnetic activity and artificial fields and radiation. Healthy humans respond to magnetic storms by an increase in the tonus of the sympathetic part of the vegetative nervous system. An important point is that the effect of magnetic sensitivity is similar to general meteosensitivity (i.e. body response to abrupt jumps of atmospheric pressure, temperature and moisture) [2]. It is significant that the above responses in the homeostatic system are the more notable the more intensive the magnetic storm is. The above mentioned reactions appear to be related to the rearrangement of neurohumoral relationships. The hypothalamus is often considered as the target and the mediator in the geomagnetic field effects of that kind. The high content of iron in the composition of biogen magnetite Fe2O3 in phylogenetically old brain structures is supposed to be one of the reasons of their magnetic sensitivity [6].

Finally, it was demonstrated by biochemical methods that electromagnetic fields of super-weak intensity affect the brain monoamines metabolism and the endogenous opioid system activation evoked by stress [5]. Thus, the magnetic field effect mechanism agrees closely on the neuro-endocrin level with the above mentioned features of stress reaction in males and females.

Summing up, it may be assumed that the above EEG-synchronisation general changes evoked by earth's magnetic field fluctuations are the electrographic component of the general stress reaction emerging during a magnetic storm. It should be noted that the relationship between EEG-synchronisation and solar activity index is weaker as compared with magnetic activity. Also it should be emphasised that the solar activity effect on the human body is mediated by the magneto- and ionosphere state.

What first of all requires an explanation is the negative sign of the correlation between EEG and solar activity (in contrast to the positive sign for magnetic activity). In this connection it is appropriate to refer to the great many investigations which revealed a sedative or sleep-like magnetic field effect on the nervous system. There are the following facts: 1) increase of the sensory and pain

threshold; 2) conditioned reflex inhibition; 3) strengthening slow-wave sleep EEG patterns. Probably it is explained by the fact that the brain sleep centre is located in the hypothalamus which is most sensitive to electromagnetic fields in according to numerous references [4].

The described magnetic field effects show that it may be not only a stress factor (as assumed earlier) but also an antistress one. The physiological mechanisms of negative and positive correlations are different. This conclusion is supported by the fact that different EEG-site pairs «respond» to both kinds of geomagnetic effects (compare fig.1A with fig.1B).

The above-mentioned two- or three-day delay of EEG response to sunbursts causes the so-called sunwind or the impact wave of corpuscular radiation. The sunwind reaches the Earth environs after1.5-3 days. As a result, magnetic effects on the Earth are delayed in relation to the events on the Sun.

The fact that remains still unclear is that EEG-synchronisation doesn't correlate negatively with geomagnetic activity while, by definition, Ap-index includes all variations of a geomagnetic field. This contradiction may be explained by the double nature of Ap-index. The prevailing part of Ap-variation determined by short-term changes of the magnetic field in the form of a magnetic storm evoked by a specific sunburst. However the average level of earth's magnetic field activity plays an important part. It changes slowly in accordance with the long sun activity cycles. These cycles are reflected in the Ap-index dynamics in the form of a slow component, which has a lower amplitude than the amplitude of abrupt changes (fig.4). It may be assumed that the average level of geomagnetic activity is at the basis of the negative correlation. In that case the abrupt fluctuations are manifested in the noise form. On the other hand the general sunspot number indicator is not affected by this noise and corresponds statistically to a certain time activity integral. Hence it reflects the slow tendency more precisely (compare 4A and 4B). If the assumption that the positive correlation between Ap-index and EEG-synchronisation is based on the stress mechanism is true, the stress may result in response to abrupt magnetic field fluctuations while the slow component can be considered as a noise. Since the abrupt changes have a higher amplitude a positive correlation is found.

Thus, we revealed a positive correlation between EEG-synchronisation and geomagnetic Ap-index. This correlation is general for most of the cortical areas but it is maximal in the frontal and central areas. Also revealed was a negative correlation between sunspot numbers and indices of local EEG-synchronisation within the left hemisphere and between the hemispheres.

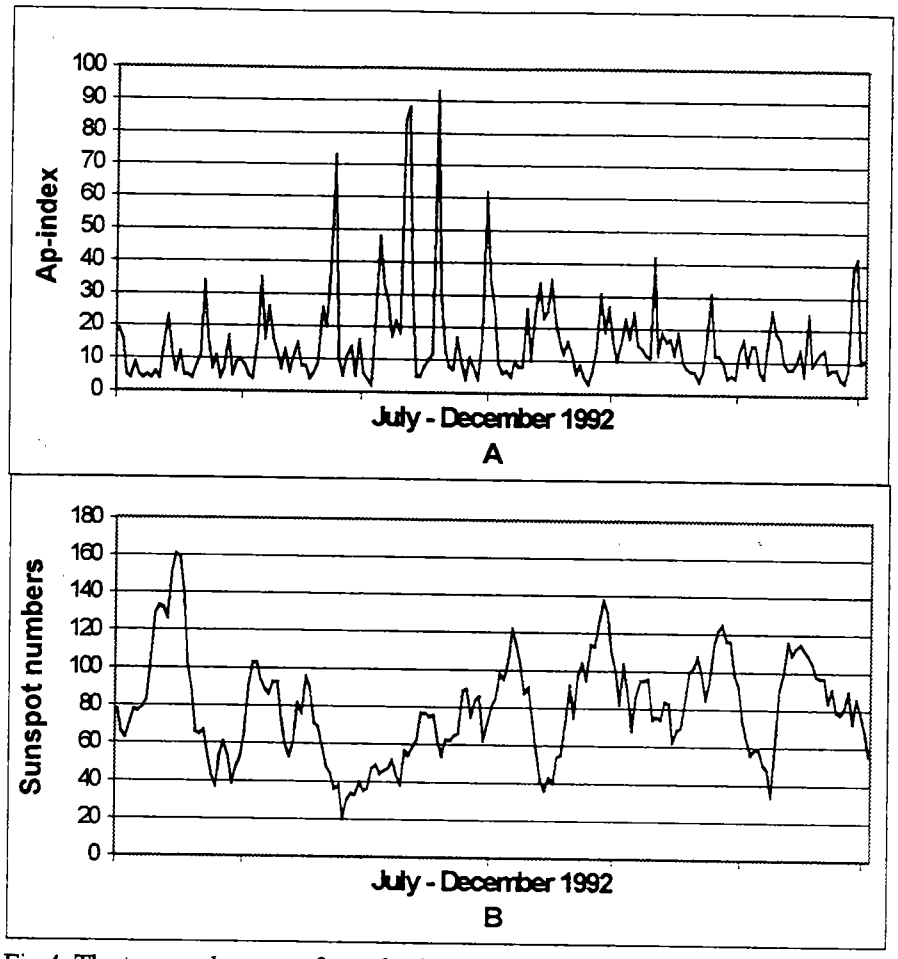

Fig.4. The temporal course of geophysical parameters under investigation
A - Ap-index; B – number of sunspots

To sum up the present discussion, one can assume, on the basis of the data obtained, that two types of central nerve system sensitivity to earth's magnetic field fluctuations are reflected in the degree of the EEG synchronisation. Increase of the global synchronisation reflects the stress reaction, arising in response to the strong short-time geomagnetic field perturbations (magnetic storms). The sedative effect of slow magnetic fluctuations is manifested locally in the indices of the EEG synchronisation within the left hemisphere and in the interhemispheric synchronisation; these indices are reduced under the increase of the mean

perturbation level of the earth's magnetosphere. Different aspects of the activation reaction and the cortical tonus related to hypothalamus activity and neurohumoral regulation are supposed to underlie both effects described.

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HYPOGEOMAGNETIC FIELDS AS ONE OF THE ADVERSE ENVIRONMENTAL FACTORS

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Until recently the main attention of the researchers dealing with the problem of the biological effects and hygienic standardisation of non-ionising electromagnetic radiation (EMR), was concentrated on studying the EMR bioeffects of anthropogenic origin, whose levels essentially exceed the natural electromagnetic background of the Earth.

At the same time a major role played by EMR of natural origin in the inception of life on the Earth and its further development and regulation was convincingly proved in the past decades.

The interest in this problem arose as far back as the first half of this century after the appearance of Russian scientists' (A.L. Chizhevskiy's and V.I. Vernadskiy's) pioneer work. Since 1960s the stream of information on the influence of natural EMR on biological objects has been steadily increasing.

In the spectrum of natural electromagnetic fields one can conditionally single out several components - the static magnetic field of the Earth (geomagnetic field - GMF), the electrostatic field and variable electromagnetic fields in the frequency band from 10^{-3} Hz up to 10^{12} Hz.

While studying the influence of natural EMF on the living matter, special attention is paid to the geomagnetic field, as one of the major factors of the environment. Is has been shown that different systems of various organisms (from bacteria up to humans) display a variety of reactions to changes of the geomagnetic field / Dubrov A.P, 1974, Chills Yu.A, 1976,1982, Moiseeva N.I, Lyubitskiy R.I, 1986/. Materials have been obtained which not only confirm the sensitivity of organisms to the geomagnetic field, but also do not exclude the probability that they are able to perceive the temporal and spatial information that it contains. It testifies that the geomagnetic field is an essential component of the environment.

Determination of the presence of biogenic magnetite in various living organisms (bees, pigeons, shellfishes, humans) allows to make the conclusion about a possibility of direct magnetoreception, as distinct from indirect, realised

via induced electrical fields / Zoeger J, Dunn J.R, Fuller M, 1981/. The study of human magnetoreception has given grounds to consider that it is present in the brain structures and in the adrenals. / Durvard Skiles, 1989/.

The constant GMF value can be changed on the Earth surface from 26 μT (in and around Rio-de-Janeiro) up to 68 μT (close to the geographical poles), achieving maxima in the areas of magnetic anomalies (Kursk anomaly up to 190 μT). The variable magnetic field (mainly generated by the currents flowing in the ionosphere and magnetosphere) is imposed on the main magnetic field of the Earth, and though its magnitude does not exceed 4-5 % of the main field, its informational influence on the biosphere can be significant /Vernadskiy V.I, 1967, Kleymenova N.G, Troickaya V.A., 1992/.

The geomagnetic field undergoes variations with long (secular) periods (8000, 600 years) and with periods counted in tens of years (60, 22, 11 years), as well as short-period daily variations.

The quasi-periodic modifications of the geomagnetic field with periods from fractions of seconds to several minutes are called geomagnetic pulsations. They are usually subdivided into regular, stable, continuous (P_t - pulsations continuous) and irregular, noise-like, pulsed (P_i - pulsations irregular). The former are observed mainly in the morning and day time, and the latter - in the evening and at night.

All kinds of irregular pulsations are elements of geomagnetic perturbations and are closely connected to them, while P_t pulsations are also observed in very calm conditions. Despite the small values of pulsation amplitudes (from several hundredths parts up to hundreds nT), a number of researchers point to the biological activity of these oscillations. It is connected, first of all, to the existing certain frequency selectivity during the interaction of a magnetic field with bio-objects and, secondly, of certain importance may be the velocity of the change in the magnetic field intensity, i.e. its derivative in time (Kleymenova N.G, Troickaya V.A., 1992). Among stable oscillations there are such, which arise day by day within the same intervals of local time. In nature, adaptation may have apparently been formed to such electromagnetic «pumping». And if the mode of stable oscillations (P_t) is «customary» for biosystems, being isolated from it can have negative consequences for an organism.

During perturbations (magnetic storm) the global excitation of micropulsations is observed, and then they can be registered for tens of hours all over the Globe.

Global and local storm activity makes its contribution to the shaping of a natural electromagnetic background of the Earth. The electromagnetic oscillations at frequencies of 4-30 Hz are practically always present. It is possible to assume, that they can act as synchronisers of some biological processes, as they are resonance frequencies for a number of them. EMR, whose origin is conditioned by storm activity, are also observed at higher frequencies (0,1-15 kHz).

Included in the spectrum of solar and galactic radiation reaching the Earth are EMR of radiofrequency, infrared and ultra-violet radiation, visible light, ionising radiation. In their totality the natural EMF of the Earth represent a whole spectrum of electromagnetic «noises», to which the Earth and all the living matter on it are exposed.

Natural EMF, including GMF, can exert an ambiguous influence on human body. On the one hand, geomagnetic perturbations are considered an ecological risk factor: There are data which indicated that the human body exposed to them develops a number of unfavourable responses. Thus it has been demonstrated that geomagnetic perturbations can desynchronise the biological rhythms and other processes in the body (Piatkin V.P, 1981), or they can be the main acting reason for the modulation of the functional status of the brain (Belisheva N.K, Popov A.N. etc., 1995). A connection has been noted between geomagnetic perturbations and the increase in the incidence of heavy medical pathologies (myocardial infarctions and insults), and also in the number of automobile accidents and aeroplanes crashes (Srivastava, Saxena, 1980, Arslanova R.M, 1982, G. Villorezy, T.K. Breus, 1995).

On the other hand, is has been revealed, that the acyclic variations of a geomagnetic field participate in the regulation of circadian, infradian and other biological rhythms, and also of their interrelations (Rigikov G.V, 1982, Diordienko I.A, 1981, Kuzimenko V.A, 1982).

Thus, now it has become clear, that natural electromagnetic fields should be considered one of the major ecological factors. And if living under exposure to natural EMF is so significant and simultaneously so «customary» for biosystems, then finding themselves in a situation where EMF levels undergo sharp fluctuations or are vastly depressed can have serious negative consequences.

Investigations of biological effects of hypogeomagnetic fields (HGMF) were began in 1960-70s in connection with the construction of surface and underground shielded structures and the conquest of the outer space. It was the complaints concerning the health status of those working inside shielded structures

(SS), which are widely used in various industries, that first made the specialists to seriously address the problem of the unfavourable influence on the body of a prolonged stay in the conditions when the levels of natural electromagnetic fields are substantially reduced. Such conditions are caused by the fact that SS, whose main function is to prevent the propagation of EMR, generated by the equipment, outside the production areas, quite naturally simultaneously hinder the penetration of natural EMR inside.

Survey of a number of specialised shielded structures has made it possible to obtain new interesting data revealing the specific features of the electromagnetic medium formed in them and unusual for humans, and first of all a substantial (**KF**= 1.5 - 15 times) reduction of the geomagnetic field levels and of the natural EMF variables, disturbance of their spatial orientation, elimination of the action of the daylight on the body, ultraviolet radiation etc. /Grigoriev Yu.G. etc., 1991, Pokhodzey L.V. etc., 1994/.

The data on the level of the weakening of GMF that we obtained in other areas and structures indicate that hypogeomagnetic conditions (HGMC) can be formed not only in specialised shielded structures. It has been shown that in underground structures of the Metro the GMF levels can be reduced 2 - 5 times, in residential and public buildings executed from reinforced concrete 1.3 - 1.5 times, in Ostankino TV-tower office rooms 1.5 - 2.3 times, and in cabins of high-speed lifts 15 - 19 times, in cabins of drilling rigs and excavators in 1.8 - 8.5 times, inside passenger cars 1.5 - 3 times, etc. People find themselves in HGMC in while flying in a spaceship or plane, in offices and cabins of river and marine ships, in submarines and other military facilities, inside bank office rooms / Pokhodzey L.V, Paltsev Yu.P, 1996/.

With that, one should especially emphasise that during magnetic storms, whose unfavourable influence on the body is felt by nearly 30% of the populations, GMF levels change, on the average, by tens of hundreds of nT, i.e. by some fractions of 1% or at most by a few percent of its magnitude. However, in the conditions described above the change in the GMF levels is as great as a few thousand nT.

Considering, that the entire evolution of the human species, as well as the shaping and life of every person as an individual, have run their course under a constant regulating influence of natural EMF, it was suggested that the deficit of these factors, so indispensable to a body's normal vital functions, can promote development of unfavourable changes in the health status of those working in such conditions.

The results of the clinical and physiological examination of those working in shielded rooms, conducted by the Institute of Biophysics and our Institute, testify to the development of functional changes in the leading systems of the body /Vasyukov G.V, Nefedov A.Yu. etc. 1992, Pokhodzey L.V, Kosova I.P, Paltsev Yu. P, 1996/.

In the central nervous system one found signs of a misbalance of the main nervous processes in the form of prevalent inhibition, brain vessels dystonia with the presence of interhemispheric asymmetry. Also noted were: an increase of the amplitude of the normal physiological tremor, longer visual-motor response to an appearing object in the mode of continuous analogue watching, reduction of the critical frequency of the merger of light glimpses.

The disturbances of mechanisms of vegetative nervous system regulation are manifested in the development of functional changes in the cardiovascular system as lability of the pulse and arterial pressure, neurocirculatory dystonia of the hypertensive type, disturbances of the process repolarisation of the myocardium.

As far as the immune system is concerned, a decrease of the total number of T-lymphocytes, concentration of IgG and IgA, and an increase of the concentration of IgE were noted.

An upward trend was reported in the incidence of diseases involving temporary occupational disability among those working in the shielded structures for a long time. With that, it was shown that among those examined the frequency of diseases accompanying the immune deficiency syndrome substantially exceeds that of practically healthy people.

Laboratory experiments data have revealed an unfavourable influence of long-time shielding from natural EMF (of different degrees of weakening) on animals. This is an essential confirmation of the role played by this factor in the development of human health status, testifying to the hygienic significance of the factor / Kopanev V.I. et al, 1979, Lednev V.V, 1991, Asashima M, 1991, Savin B.M. et al, 1991, Grigoriev Yu. G, 1995, Pokhodzey L.V, Paltsev Yu.P, 1998/.

RAMS Institute of Occupational Medicine conducted a series of experimental investigations to evaluate the bioeffects on the leading functional systems of animals placed in shielded cameras (GMF weakening coefficient = 100 and 500 times) for different lengths of time (from 0.25 up to 24 hours daily, the total number of sittings being from 1 up to 120).

The study of the CNS functional status revealed some changes in the EEG- and conditional reflex activities of animals, testifying to a disturbance of the nervous processes which were biased towards inhibition. The endocrine system responded by a decrease of the gonadotropic hormones activity of the pituitary body – both follicle-stimulating and luteinizing, and an increase of the corticosterone activity. Oestrous cycle elongation as well as morpho-functional changes in the ovaries and uterus were noted in the reproductive system. The changes in the status of the humoral and cellular links of the immune system of animals were revealed.

The level and direction of the changes found display a certain dependence on the length of stay in hypogeomagnetic conditions. The intermittent influence of HGMF produced more expressed bioeffects on the part of separate systems of the body as compared to the constant one, especially at the initial stage of the action.

A theoretical analysis of the physical mechanism of HGMF biological effects leads one to suspect, that magnetoresonance effects, determining the physical and chemical changes in biological structures form the basis of the HGMF biological effect.

Thus, the above data testify to a hygienic significance of hypogeomagnetic conditions and indicate the necessity of their appropriate regimentation.

So far there have been no hygienic recommendations regulating the action of weakened GMF on humans anywhere in the world.

On the basis of the analysis of the findings of the HGMC hygienic investigations conducted at various industrial facilities, of the health status of those working under exposure to different degrees of weakened GMF, of the animal experimental data, a draft of hygienic standards called "Tentative permissible levels (TPL) of hypogeomagnetic field intensity reduction at working places". In accordance with that document, TPL of hypogeomagnetic field intensity reduction at working places inside facilities, premises, technical devices during a working shift should not exceed 2 times as compared to its intensity in the open space in the adjoining area.

Methods have been developed to provide a hygienic evaluation of the reduction of geomagnetic field intensity inside facilities, premises, and technical devices. Special instruments (magnetometer of MF-1 type, meter of strength of static magnetic fields of IMP-3 type), suitable for prompt hygienic monitoring of

hypogeomagnetic conditions have been produced /Pokhodzey L.V, Shomenko A.N, 1991, etc./.

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PHYSICAL MECHANISMS OF ACTION OF WEAK STATIC AND ALTERNATING MAGNETIC FIELDS ON BIOSYSTEMS

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The problem of the effect of magnetic fields on living objects is more than a century old. There is a great number of reports on the biological and biomedical effects of static (SMF) and alternating (AMF) magnetic fields [Friedman et al, 1963; Kholodov, 1970; Savitz et al, 1988; and others]. It is common knowledge that some persons are sensitive to magnetic storms. Unfortunately, this area of biology has two defects. First, no serious theoretical physical foundation of the magnetic field action on biosystems has been developed yet. Second, the experimental evidence is not very convincing because of the poor reproducibility of these results [Morgan, Nair, 1992]. Beginning from 1985, after the remarkable works by Liboff [1985] and Blackman et al. [1985], attention of many researchers has been focused on a surprising phenomenon: the effect of a low frequency AMF, that manifested itself as a change in free calcium concentration in extra- and intracellular media, turned out to be highly dependent on the simultaneous presence and magnitude of a SMF. The SMF and AMF fields were very weak, being comparable in their magnitude with the natural geomagnetic field. The greatest effect was observed at the AMF frequency close to the cyclotron frequency corresponding to a calcium ion and the applied SMF field. Subsequently various experiments [Smith et al, 1987; Rochev et al, 1990; Yost, Liburdi, 1992; Blackman et al, 1994; Deryugina et al, 1996; and others] confirmed the existence of this effect.

A series of attempts to understand the mechanism of the above phenomenon were taken. In 1985 Liboff [1985] advanced a model that considered an ion executing a circular motion under the influence of combined SMF and AMF magnetic fields and experiencing the cyclotron resonance at the cyclotron frequency of the AMF field. This model initiated the physical analysis of the above effect, but unfortunately the effect considered there was impossible because of viscosity of the liquid medium and an extremely great radius of the ion circulation measured in meters (which greatly exceeds not only the cell dimensions but also those of the whole body) at the room temperature and the weak fields close to the geomagnetic one. In other models [Zhadin, Fesenko, 1990; Edmonds, 1993; Muehsam, Pilla, 1994] the precession of ion thermal motion in magnetic fields was considered, but the resonance effects were not sufficiently studied and the energy problem was not solved. Lednev [1989, 1991] tried to explain the above effects by the Zeeman splitting of energetic levels of an ion in a macromolecule under the

influence of an SMF field and by the parametric resonance in the ion oscillation under the action of an AMF field. The attempts to use the parametric resonance as a possible mechanism of action of weak low frequency AMFs in combination with weak SMFs were undertaken by other researchers too [Zhadin, Fesenko, 1990; Blanchard, Blackman, 1994]. Recently Lednev [1996] advanced the idea that the parametric resonance can cause polarisation of ion oscillation inside a macromolecule that, in Lednev's opinion, can be of biological significance.

However, in spite of all the attractive features of the above-mentioned models based on the parametric resonance, we have to note regretfully that such resonance cannot take place at weak SMFs and low frequency AMFs. As was shown in the works of Mandelshtam [1972] and Landau and Lifshitz [1958], the parametric resonance can develop only at not very big ratios of the natural frequency of an oscillator (in our case, the natural frequency of the ion oscillation in a macromolecule) to a frequency of changes in a parameter (in our case, the frequency of the AMF) acting on the natural frequency of the oscillator in question. Earlier, we [Zhadin, 1996] derived the equation of the ion motion in a macromolecule under the combined action of SMF and AMF and reduced this equation to the equation of parametric resonance. Even at very small values of the damping coefficient such resonance can take place at the above ratio of the order of 10-100. But in real conditions of the ion motion in a macromolecule and the acting magnetic fields, this ratio is of the order of 10,000,000, which completely eliminates the possibility of the development of the parametric resonance even in its weakest manifestation. To do this would require either incredibly small values of the damping coefficient many orders of magnitude less than 1 rad/s for the ion oscillator, or extremely high frequencies of the AMF measured in hundreds of MHz, or huge amplitudes of the AMF many orders of magnitude more than the geomagnetic field.

The main problem of the biological action of weak magnetic fields is the energy problem: the way these fields could change the energy of the motion of particles in a biological macromolecule so much exceeding the energy of its thermal motion that it would be able to change the quantum state of this macromolecule. In fact, it was this problem that proved to be the stumbling block for all the above theoretical models. In the present article our attention is focused on this problem.

We [Zhadin, 1996, 1998] derived, analysed and solved the equation for thermal motion of an ion in a macromolecule under the influence of SMF and low frequency AMF:

$$\frac{d^2\mathbf{r}_o}{dt^2} = -\gamma\frac{d\mathbf{r}_o}{dt} - \omega_0^2\mathbf{r}_o + \frac{q}{m}\left[\frac{d\mathbf{r}_o}{dt}\times\mathbf{B}\right] + \frac{q}{2m}\left[\mathbf{r}_o\times\frac{d\mathbf{B}}{dt}\right] + \mathbf{F} \qquad (1)$$

The equation is given in the vector form. Here $\mathbf{r}_o$ is the radius-vector of the ion position originating at the equilibrium point of the ion, its absolute value is equal to $\sqrt{x^2+y^2+z^2}$ where x, y and z are the Cartesian co-ordinates of the ion; t is the time; q and m are the charge and the mass of the ion; **B** is the total SMF and AMF magnetic field; γ is the damping coefficient; ω_o is the natural frequency of the ion oscillation in the macromolecule; **F** is the total force of action of surrounding particles on the ion that causes the thermal motion of the ion near its equilibrium point; the bold letters denote vectors and the square brackets symbolise vector products. On the left there is ion acceleration. On the right the first term takes into account the damping processes; the second one is determined by the force of the intramolecular potential field restoring the ion to its equilibrium point; the third term is the Lorentz force of the magnetic field action on the moving ion which manifests itself in precession, that is in the rotation of the trajectory of the ion thermal motion around the magnetic field line with a varying angular frequency; the fourth one results from the force made by the curl field generated by the time-varying magnetic field. In the following, we considered the parallel magnetic fields algebraically summed: the SMF field, B_o, and the AMF field, $B_{AC} = B_1\cos\Omega t$, harmonically varying with the amplitude B_1 and the angular frequency Ω. These fields are taken as directed along the z-axis.

At a small frequency Ω of the AMF, much less than the ion natural frequency ω_o and weak SMFs and AMFs, much less than $2m\omega_o/q$, the angular velocity of the precession of the ion trajectory is equal to

$$\frac{d\varphi_0}{dt} = \Omega_L(1+\beta\cos\Omega t) \qquad (2)$$

and does not depend on the frequencies ω_o [Tamm, 1989]. Here $\beta = B_1/B_o$ is the ratio of the amplitude of the AMF field to the SMF field and φ_o is the angle between the x-axis and the projection of the radius-vector $\mathbf{r}_o$ on the (x,y)-plane; Ω_L is the so-called Larmor frequency $\Omega_L = \frac{q}{2m}B_0$ presenting the precession

frequency of the ion motion trajectory in the SMF magnetic field, B_0. Since the magnetic fields are along the *z*-axis, the ion rotates in the (*x*,*y*)-plane and the magnetic fields do not influence the ion motion along the *z*-axis. So further we only consider the ion motion in the (*x*, *y*)-plane and the projections of all the forces, including the thermal driving force **F**, on this plane. Moreover, for simplicity we only considered the projection of the force **F** on the *x*-axis which was further denoted as *F*(*t*).

Let us now turn from the motionless co-ordinate (*x*,*y*,*z*) system to the moving one (x_1,y_1,*z*) rotating about the *z*-axis with the variable angular velocity $d\varphi_0/dt$ of the precession (2). The cylindrical co-ordinates (*r*, φ, *z*) are convenient here. Then φ_o is the angle between the circulating x_1-axis and the motionless *x*-axis, *r* is the distance between the origin of the co-ordinates and the ion position in the rotation co-ordinate system, φ is the angle between the *r* and the x_1-axis. In these conditions, in the rotating co-ordinate system the inertial forces - the centrifugal force, the Coriolis one, and the inertial one, caused by unsteadiness of the co-ordinate system rotation, add to all the previous forces. But because the Coriolis force is equal and oppositely directed to the Lorentz force, equation (1) is substantially simplified and takes the following form:

$$\frac{d^2r}{dt^2}+\gamma\frac{dr}{dt}+[\omega_0^2+\Omega_L^2\Phi(t)]r = F(t)\cos(\Omega t + b\sin\Omega t), \qquad (3)$$

$$\frac{d^2\varphi}{dt^2}+\gamma\frac{d\varphi}{dt} = 2\beta\Omega_L\Omega\sin\Omega t, \qquad (4)$$

where $\Phi(t)$ is the function harmonically varying. On the right of Eq. (3) there is a projection of the driving force *F*(*t*) on the circulating radius *r* with which it makes the angle $\varphi_o+\varphi$ determined by solving Eqs. (2) and (4). At small values $\gamma << \Omega$, the sum $\varphi_o+\varphi$ takes the simple form $\varphi_o+\varphi = =\Omega_L t - b\sin\Omega t$. For brevity the designation $b = \beta\Omega_L/\Omega$ is introduced here. As was shown earlier [Zhadin, 1996, 1998], at gigantic frequencies ω_o the kinetic energy of the ion angular oscillation $\varphi(t)$ is infinitesimally small, therefore the thermal driving force *F*(*t*) was not considered in Eq. (4). In Eq. (3) the function $F(t)$ can be expanded in the Fourier

series and the function $\Phi(t)$ can be expressed as a sum of cosines. Then Eq. (3) may by shown as the equation

$$\frac{d^2r}{dt^2}+\gamma\frac{dr}{dt}+\omega_0^2\left[1+\frac{\Omega_L^2}{\omega_0^2}\sum_{k=0}^{k=2}D_k\cos(k\Omega t)\right]r=\sum_{n=1}C_n\cos(\omega_n t+\delta_n)\cos(\Omega_L t-b\sin\Omega t) \quad (5)$$

known as the inhomogeneous Hill equation [Whittaker, Watson, 1927] that describes the phenomenon of parametric resonance in the generalised form. The parametric resonance could arise at certain discrete values of the frequency Ω of the AMF field and the frequencies ω of thermal action of surrounding particles on the ion, i.e. the frequencies of the driving force $F(t)$, would be the most prominent at the relationship $\Omega=2\omega_0$, and could take place at subharmonics of the frequency $2\omega_0$. However, in actual practice the frequencies ω and ω_0 are about 10^7-10^8 times higher than the frequencies Ω and Ω_L. At so enormously high order of subharmonics the occurrence of the parametric resonance is impossible [Mandelshtam, 1972; Landau, Lifshitz, 1958]; to do this would require unbelievably low values of the damping coefficient $\gamma<<1$, close to oscillation in the cosmic vacuum, that is far from being comparable to the natural intramolecular conditions. The impossibility of parametric resonance can be seen in Eq. (5) where the coefficients D_k are of the order of unity and the ratio Ω_L^2/ω_o^2 is of the order of 10^{-16}; therefore in Eq. (5) the second item in the square brackets, responsible for the parametric resonance development, does not change the ion motion and the ion kinetic energy in no way.

Is there any need to make the assumption of the parametric resonance development, so incredible under these circumstances, in the search for a mechanism of primary biological detection of weak magnetic fields? We [Zhadin, 1996, 1998], have investigated this problem in detail.

Let us agree with the absence of parametric resonance in these conditions and put the ratio $\Omega_L^2/\omega_o^2\sim10^{-16}$ just equal to zero, as it is the practice even at $\Omega_L^2/\omega_o^2\approx10^{-4}$. Because of the linearity of Eq. (5), its solution is the sum of solutions for every item of the sum in the right-hand side. So suffice it to consider only one of these items with the phase shift $\delta=0$, denoting $C=C_k$ and $\omega=\omega_n$. Taking into account that at $b\le1/2$ the approximations

$\cos(b\sin\Omega t) \approx 1 - \frac{b^2}{4} + \frac{b^2}{4}\cos 2\Omega t$ and $\sin(b\sin\Omega t) \approx b\sin\Omega t$ are rather accurate, we are led to the following long, but simple equation of constrained oscillation:

$$\frac{d^2r}{dt^2} + \gamma\frac{dr}{dt} + \omega_0^2 r = -\frac{C(\omega)}{2}\left\{\left(1-\frac{b^2}{4}\right)[\sin(\omega+\Omega_L)t + \sin(\omega-\Omega_L)t] + \right.$$

$$\frac{b^2}{2}[\sin(\omega+\Omega_L-2\Omega)t + \sin(\omega-\Omega_L-2\Omega)t + \sin(\omega-\Omega_L+2\Omega)t + \sin(\omega+\Omega_L+2\Omega)t] +$$

$$\left. + \frac{b}{2}[\sin(\omega+\Omega_L-\Omega)t + \sin(\omega-\Omega_L+\Omega)t - \sin(\omega+\Omega_L+\Omega)t - \sin(\omega-\Omega_L-\Omega)t]\right\} \qquad (6)$$

On the right there is a sum of ten sines. The solution of Eq. (6) is the sum of harmonic solutions of the type

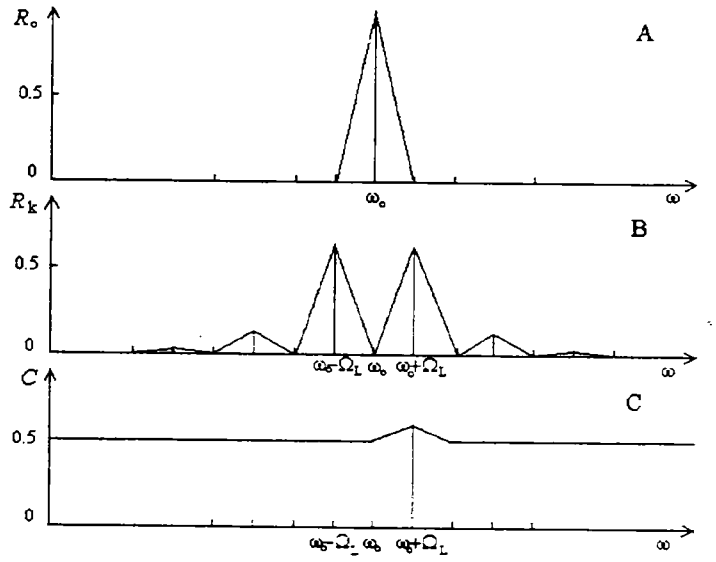
$$r_k(t) = \frac{A_k\sin(\omega_k t - \phi_k)}{\sqrt{\left(\omega_0^2 - \omega_k^2\right)^2 + \gamma^2\omega_k^2}}, \text{ where } \tan\phi_k = \frac{\gamma\omega}{\omega_0^2 - \omega^2}.$$

Here the index k marks the separate harmonic processes in the right-hand side of Eq. (6) and ω_k is the total frequency in the round brackets for each process. At certain relationships: $\omega = \omega_0 \pm \Omega_L$, $\omega = \omega_0 \pm \Omega_L \pm \Omega$ and $\omega = \omega_0 \pm \Omega_L \pm 2\Omega$, the frequencies ω_k and ω_o become equal to each other and the resonances occur. These resonance solutions have the form:

$$r_{kres}(t,\Omega) = \frac{C(\omega)R_k\sin(\omega_0 t - \phi_k)}{2\gamma\omega_0}, \qquad (7)$$

where $C(\omega)$ are the amplitudes of the driving force at the frequencies ω determined by the foregoing relationships, and R_k are the relative amplitudes of the harmonic processes in the right-hand side of Eq. (6) equal to $\frac{1}{2}\left(1-b^2/4\right)$,

$b/4$ or $b^2/16$. In the resonant oscillation, the velocity of the ion and its kinetic energy, proportional to the velocity squared, do not depend on the frequency ω_o, that may be checked by differentiation of expression (7) with respect to t at which the ω_o is cancelled.



Scematic sketch of relationships between the relative amplitudes of the ion resonant frequencies R and the spectrum C of the thermal driving force

Thus, at switching on parallel SMFs and AMFs with a certain frequency, the diversity of new resonance peaks at different frequencies ω appears instead of one initial resonance peak at the frequency ω_o, which results in the disturbance of the original thermodynamic equilibrium and in the establishment of a new thermodynamic equilibrium at the new resonant frequencies. During the processes of setting new relationships between these particles the thermal energy of the ion can experience short-term, but remarkable variations in its value upward or downward. At the cyclotron frequency $\Omega = 2\Omega_L$ of the AMF, the summation of the highest resonance peaks occurs and the resonance at this frequency comes into particular prominence at $b>0$. The sign of b is determined by the initial phase of the AMF field at its switching on: at $B_1<0$ we have $\beta<0$ and $b<0$, and vice versa.

These phenomena can be schematically demonstrated by the figure given below. There **A** is the spectrum of the ion oscillation in a macromolecule with only one resonant frequency ω_o; **B** is the spectrum of the new resonant frequencies after switching on the magnetic fields; **C** is the spectrum $C(\omega_k)$ with a local rise around the frequency $\omega_o + \Omega_L$. In principle, the spectrum $C(\omega_k)$ of the driving force of the thermal action, exerted on the ion by the group of the nearest molecular particles, most probably has a line form like spectra of other atomic and molecular structures, and is more non-uniform than it is illustrated in the figure. For simplicity the form of the resonance peaks in the figure was assumed to be triangular with the half-width equal to $\gamma = \Omega_L$. The new resonant frequencies can be non-coinciding with spectral peaks of the driving force or, conversely, can coincide with some other peaks of the driving force spectrum. In both cases, after switching on the magnetic fields the thermal energy of the ion must experience short-term changes during the process of establishment of the new thermodynamic equilibrium. After switching off the magnetic fields the inverse thermodynamic realignment and changes in the ion thermal energy, identical in amplitude and duration, but opposite in sign in reference to those after switching on the fields, must occur. The splitting of the original resonant peak into two neighbouring resonant peaks arises, as is easy to see (the first square brackets in the right-hand side of Eq. (6)), at switching on the SMF field alone (Zeeman-effect) without any AMF field, and in this case the essential changes in the ion thermal motion can take place too. The AMF magnetic field alone can exert the action as well. At $B_o = 0$ we have Ω_L and $b = qB_1/2m$; five sines remain in the right-hand side of Eq. (6), and there are five resonant frequencies with one of them equal to initial ω_o. But the combined action of the SMF and AMF fields initiates the number of new resonant frequencies considerably greater than the SMF or AMF field alone; in this situation the probability of a change in the ion thermal motion is higher, and at the cyclotron frequency of the AMF the resonance peak is higher than any resonance peak at the SMF or AMF alone.

The damping coefficient γ is a factor of great importance for this sort of effects. Within the macromolecular cleft where the ion is shielded from immediate impacts of water molecules, as was shown by theoretical analysis [Chiabrera et al, 1991], there are unique conditions for ion oscillation with very low damping, close to dilute gas. Muehsam and Pilla [1994] take this value as $\gamma \sim$1-40 rad/s. A simple estimation [Zhadin, 1998] supports this possibility. The mass of a calcium ion is 10^5 times greater than the electron mass. Interatomic distances in a macromolecule are about $10^{1,5}$ times greater than atomic dimensions. So the

restoring forces for an ion are about 10^3 times greater as for an atomic electron and the frequencies of the ion oscillation $\omega = \sqrt{k/m}$, where k is the coefficient of restoring force, are at least 10^4 times less than those for atomic electrons, even though the amplitude of electron oscillation is taken as equal to the entire atomic size. At room temperature, frequencies of atomic electron are about 10^{14} rad/s, and consequently the ion frequencies ω would be expected to be about 10^{10} rad/s. Let us take that the quality Q of the ion oscillation in the macromolecular cleft has the same value as the atomic electron oscillation: about 10^7 [Gorelik, 1959], that is a lower boundary estimate for the ion, considering its smaller radiation loss and its better protection from the surrounding medium compared to outer atomic electrons. Then the damping coefficient of the ion oscillation $\gamma = \omega/Q$ is not more than of the order of 10^3 rad./s according to this upper estimation.

The full width at half maximum for the resonance peak is equal to γ. For the resonance peaks to be discernible, their half-width must be at least equal to the expected distance between them, i.e. $\gamma \approx 2\Omega_L$. The cyclotron frequency for a calcium ion in the geomagnetic field about 50 μT is about 240 rad./s, that is corresponds to $\gamma \approx 10^{2.5}$ rad/s, comparable to the just obtained estimate. Thus the resonance peaks would be expected to be discernible in the spectra of ion oscillation and of the driving thermal force, especially knowing that our estimate for γ value was upper. Hence it follows [Zhadin, 1998] that the magnetic fields about 50 μT can cause short-term local changes in the ion energy measured by several degrees, or even tens of degrees centigrade in relation to the equilibrium temperature of the ion, which can be enough to trigger alteration in the quantum state of a macromolecule. Calculations have shown that, for the situation displayed in the figure, the increase in the ion thermal energy at switching on the magnetic fields is equal to an enormous value - as high as 30°C. If after switching on the fields the short-term decrease in the ion thermal energy occurs, that does not influence the ion state in the molecule because of its downward direction; after switching off the fields the increase in the energy, the same in magnitude, will arise, in connection with that either switching on or off the fields in both cases will give a certain increase in the ion thermal energy, which can turn out to be able to change the conformation state of the macromolecule. Deriving Eq. (5), to simplify its form, we took γ as being small compared to Ω. When this condition is not

met, the value b decreases somewhat and some phase shift between the resonant processes summed arises, but that can be compensated to a degree by proper adjusting of the initial phase of the AMF field at its switching on and the general features of the resonance phenomena considered here do not change.

Thus, without recourse to the more than questionable proposal about parametric resonance development, we managed to reveal the possibility of primary detection of weak SMF and AMF magnetic fields, acting individually and in combination, by macromolecules, with the most prominent effect at the cyclotron frequency, that is observed experimentally. The thermal noise, being the main obstacle for the previous theories of the primary biological detection of weak magnetic fields, is a necessary link in the mechanism of their action in our theory. It is worthy of note that the mechanism considered here depends on many factors: for development of these effects at the cyclotron frequency, it is necessary that the values of the driving force spectrum at the frequencies ω_o and ω_{res} should be sufficiently different, that is determined by a specific structure of the nearest surrounding of the ion and a particular SMF field magnitude, even though the AMF frequency is kept as cyclotron one when the SMF field changes. So at one SMF magnitude the effect can appear while at another it can disappear, though the frequency of the AMF would remain the cyclotron one in both cases. Besides, as noted above, the resonance at the cyclotron frequency depends on the initial phase of the AMF field, when the resonance peaks may be added, or subtracted or displaced in phase. It is all these factors that are evidently the reason of weak reproducibility of magnetic field effects experimentally observed, causing distrust of bioelectromagnetics as a whole [Morgan, Nair, 1992].

The effects studied here can take place in calcium-binding proteins, as an example, provoking release of calcium ions into the cytoplasm. In this case even very small changes in the free calcium concentration at a level of $10^{-6} - 10^{-7}$M can lead to a great diversity of manifestations in all the systems in an organism, because the free calcium is a second messenger in chains of intracellular signalling [Permjakov, 1993]. These effects, as was noted earlier [Zhadin, 1996, 1998], can occur in the interior of microcrystals suspended in water, causing the short-term heating of the microcrystals and their partial dissolving. It is interesting that they are opposite in their direction to the known [Chernobai, 1971] influence of very strong magnetic fields on crystallisation, most likely connected with diamagnetic features of all atoms and molecules. But the effects studied by us cannot take place in small molecules and liquid crystals in the water medium where values of the damping coefficient γ are many orders more than the values considered here.

We performed a set of experiments on investigation of combined action of parallel weak SMF and AMF on different objects. The influence of these fields on the electric features of aqueous solution of amino acids were studied [Novikov, Zhadin, 1994; Zhadin et al, 1998]. The method of preparing the solution was such that the solution was a two-phase medium with suspended amino acid microcrystals: the saturated solution was prepared at elevated temperature, which lowered subsequently. At switching on the combined SMF and AMF magnetic fields, the short-term increase in the electric current passed through the solution was observed if the AMF field frequency was equal to the cyclotron frequency of the amino acid dissolved. This effect can be attributable to the short-term heating of the interior part of the microcrystals followed by the partial dissolving of these microcrystals that led to the delivery of a small additional portion of the amino acid ions to the conducting medium of the solution after switching on the magnetic fields. Then all the system came to the equilibrium again.

We [Deryugina et al, 1996] also carried out the experiments on combined action of the parallel SMF and AMF magnetic fields on rat behaviour in the "open field" test. It was revealed that the fields with the calcium cyclotron frequency lowered the locomotor and investigating activity of the animals and the fields with the magnesium cyclotron frequency increased the level of these forms of activity. Such mutually opposite influence of the fields with the frequencies mentioned was likely connected with the competition of the calcium and magnesium ions for the same binding centres in calcium-binding proteins [Permjakov, 1993]. The fields with the magnesium cyclotron frequency, facilitating the release of magnesium ions from the calcium-binding proteins, made these proteins capable to the capture of calcium ions from the cytoplasm and thus decreased the free calcium concentration in the cell. On the other hand, the fields with the calcium cyclotron frequency, releasing calcium ions from the calcium-binding proteins, conversely, increased the free calcium concentration in the protoplasm and caused the opposite effects.

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RESONANCES AT COMBINED ACTION OF STATIC AND LOW-FREQUENCY MAGNETIC FIELDS ON MODEL SYSTEMS

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Resonances or " windows of sensitivity " at combined action of weak static and low-frequency alternating magnetic fields (the SMF and the AMF accordingly) on bio-objects or on physical-chemical systems are one of the basic components of a more general problem - that of the influence of weak magnetic fields (MF).

As recently as 15-20 years ago a significant part of the scientific community ignored this problem. The results of experiments, which testified to the influence of the weak MF, to say nothing of the effects of SMF and AMF synergy, were considered as artefacts.

It was largely caused by general theoretical reasoning that the energy E of weak MF interaction with matter is much less than kT, where k is Bolzman's constant and T - absolute temperature. The critical attitude was also stimulated by poor reproducibility of the results even if the experiments were repeated in the same laboratory and on the same device.

For the first time the strict and reproducible results of the influence of the weak SMF and the AMF on chemical reactions with the participation of radicals were obtained by R.Z.Sagdeev and K.M.Salikhov et al. (Novosibirsk), by E.L.Frankevich et al. and by A.L.Buchachenko (Moscow). The explanation of the mechanism was based on new manifestations of the spin exclusion in the radical reactions under the influence of interactions of a magnetic nature (Zeeman's and hyperfine), which were discovered. Being controlling in nature they can «work» even if the energy of the magnetic interactions is much less than the energy of the thermal movement of molecules (see, for example, /1/).

The effects of synergy in the combined influence of the weak SMF and the AMF came to light for the first time by S.M.Bawin and W.R.Adey, by A.H.Jafary-Asl et al. and by C.F.Blackman et al.

It was pointed out that in the phenomena discovered the nuclear magnetic resonance (NMR) and electronic spin resonance (ESR) might play a possible role.

However it was difficult to understand, how little deviations from equilibrium population can result in appreciable biological effects. V.N.Binghy has

shown /2/ that in some sites of biophysical systems, which are responsible for key biochemical reactions in the systems and at the same time are protected from external environment, the nuclear spins can play an appreciable role.

The effect of synergy of the weak SMF and the AMF was rather unexpectedly manifested also in the so-called ionic (or biological) cyclotron resonance (ICR) (A.R.Liboff).

The SMF acts in this phenomenon as a controlling field. It is generally accepted that in the ICR it is only the AMF component, which is collinear to the SMP, that acts, unlike the ESR and the NMR, where orthogonality of the SMF and the AMF is essential.

It has repeatedly been emphasised that the geomagnetic field (GMF) can also act as a controlling field. It is the failure to take into account the GMF in investigations on the biological action of the AMF that may explain the apparently poor reproducibility and contradictory results of some experiments, carried out even in the same laboratory and, of course, in laboratories located elsewhere.

The influence of the GMF on the results of experiments is not news. We would like to remind our readers that as far back as 1923 the famous American physicist professor R.Wood made, as he put it, "a wonderful discovery". Coming back to his laboratory in the autumn, he failed to obtain the optical phenomenon (a strong polarisation of mercury vapour fluorescence, excited by dark blue radiation of a mercury arch) which he had observed in the spring, although he used the same the device. The polarisation completely disappeared. The only difference was that the device had been moved. After professor R.Wood moved the device to its previous place the effect immediately reappeared /3/. Until that time nobody had ever found that such a weak SMF as the GMF might influence optical phenomena.

Let us touch on some theoretical explanations of the ICR phenomenon, but very briefly, taking into account the large number of the conference reports devoted to this problem.

Originally the explanations were reduced to models, based on the assumption of a cyclotron movement of ions in the ionic channels of cell membranes. These models were subjected to valid criticism. Moreover, V.V.Lednev et al. showed for the first time / 4 / that the ICR can also be observed in solutions.

The theory, advanced by V.V.Lednev / 5, 6, 11 /, explains the ICR phenomenon by the interaction of the collinear SMFs and AMFs with an ion bound with protein. In / 5, 6 / an analogy to the parametric resonance is drawn. This variant of the theory was modified by J.P.Blanchard and C.F.Blackman / 7, 8 /. The discussion concerning the suggested updating of the theory and the experiments / 9 /, which, in Blanchard and Blackman 's opinion, corroborate the validity of their theory, is contained, for example, in / 10 - 16 /. In the variant of Lednev's theory /11/, the ICR is caused by changes of a spatial polarisation degree of a bound ion vibration. A case "of magnetic vacuum" is briefly considered also.

For critical remarks see, for example, / 17, 18 /.

The mechanism proposed by V.N.Binghy attracts attention / 18 - 20 /. The ICR is explained as the effect of the interference of long-lived quantum states of ions in protein capsules. In the MF, modulated in a certain manner in time, the interference brings about the redistribution of ion probability density and its transformation to slowly rotating antinodes. For a case of non-linear dependence of ion-protein dissociation probability P on the probability of stay of an ion near the P capsule "gate" is found as the function of the appropriate parameters of the problem. It is essential that the parameters include the nuclear spin of an ion. The theory also predicts which effects are possible to expect at the molecular level in hypomagnetic conditions.

A number of models was suggested by A. Chiabrera et al. (see, for example, / 21 - 22/). For critical remarks see, for example, /16/.

Unfortunately, we have no possibility of dwelling on other theories of the ICR phenomena.

The theoretical predictions of the dependence of the ICR for a given ion on the appropriate parameters (SMF and AMF intensity, their ratio, frequencies of harmonics and subharmonics, on which ICR is observed etc.) appreciably differ in different theories.

However, the results of the experimental researches make it yet impossible to confidently prefer any of the suggested mechanisms.

Practically all known researches have been carried out in the area of very low frequencies, weak SMFs and with the harmonic (sine wave) AMF.

Of course, it is very important and interesting.

But for a more intimate understanding of the ICR phenomenon other questions, in our opinion, may be no less interesting.

1. How far does the SMF-AMF synergy extend towards the SMF intensities and the harmonic AMF frequencies, much greater than those usually investigated? Are the same general laws valid that act in the area of the weak fields? In particular, does the AMF, which is orthogonal to the SMF, influence the effect?

2. What is the effect of the combined influence of the SMF and two or more harmonic AMF? For example, what is the effect in the case, when the half-sum of the frequencies corresponds to the maximum of the resonance, the frequencies (from the right and from the left) are outside of the resonance and the AMF modulation, which is caused by the beats, is slow? The question is of interest as fundamental and practical simultaneously because at the moment the biological effects, arising due to two and more AMF (in general, the EMF), can be predicted correctly only by thermal models.

3. To what extent are biological or physical-chemical systems capable of, while exposed to the action of the non-sinusoidal AMF, whose Fourier series does not involve a fixed term, and with the addition of the collinear SMF, which corresponds to the resonance of this term, distinguishing such harmonics? Whether or not some system react only to the saw-tooth AMF if the frequencies of the saw-tooth AMF, the triangular AMF and the square AMF are equal, for example, to the half of the cyclotron frequency? What different biological effects may be produced by the nonsinusoidal magnetic fields whose Fourier series differ by values and signs of some terms?

4. What will be observed at the modulation of the AMF and at AMF bursts of a different length? Can the addition of a noise to SMF and AMF affect their synergy?

5. Can the fixed term of Fourier series of the non-sinusoidal AMF play the role of the control parameter of the ICR? If the SMF intensity is equal to zero, whether or not the ICR will be observed at the action, for example, of the unipolar square AMF only in some "quantum" intervals of AMF amplitudes depending on the duration and the frequency of the pulses?

6. Can the ICR, in the case of a rotating magnetic field (RMF), be determined by the RMF- ICR frequency ratio? Does it explain, why in some cases so-

called "turbotrons" do not produce a beneficial medical effect if moved or their orientation is changed?

The list of these questions can be continued.

The answers are important in terms of application and fundamental research.

Unfortunately the knowledge, that the intensity and the direction of the SMP in many cases are "a control stick" for a forced tuning or off-tuning of the response of an object to the AMF of a given frequency, amplitude and direction, does not simplify the search for effects of the SMF-AMF synergy.

The usual technique calls for a consecutive series of experiments with a given SMP vector, by changing discretely the frequency and the amplitude of the collinear AMF.

With the purpose of some simplification of the search for and the investigation of the SMF -AMF synergy effects (including the ICR) we suggested the tomographic principle for use in magnetic devices.

According to this principle, in the working volume, side by side with the collinear SMF and the AMF of the high degree of uniformity, an additional independent collinear gradient SMF is created. As a result, there arise planes of isointensity of the MF with various ICR conditions. The groups of researched objects are placed in these planes. Depending on the value of the gradient for the given AMF frequency and the SMF intensity a different «expansion» of the resonance line or the lines may take place. The search for the synergy effects can occur simultaneously for a relatively great number of objects, which are in the one and the same working volume with other conditions being the same. Changing the value of the gradient, it is possible to change the scale of the dependence "effect - field" for a given frequency. If the gradient is great enough to remove some part of the working volume from resonance conditions, background samples can be located in this part also.

The device can be made of two components provided that the axis of one magnetic system is previously oriented along the complete vector of the geomagnetic field. It substantially simplifies its design and adjustment in comparison with the three-component variant.

The results of measurements, carried out by the usual method and by the tomographic method, may be compared by a reconstruction of the dependence "effect-frequency (at the given field)» into the dependence "effect - field (at the given frequency)".

It is possible to hope that using the devices made on the basis of the tomographic principle, will simplify the search for and investigations of effects of the SMF-AMF synergy.

The advantages of this approach should apparently be displayed during researches in an area of much higher SMF intensity and AMF frequencies than those usually accepted. It is true that the higher the SMF the greater time the standard experiment technique will occupy, and it will also require the fulfilment of other rather rigid conditions of the experiments.

An approach, somewhat similar to the tomographic principle, may be also implemented in usual magnetic systems (for example, for Helmholtz's configuration etc.) by creating a misbalance of the currents in the coils or simply by placing objects in areas with different SMF intensities instead of a uniform field. It has been used by the authors of / 9 /, but for research of the dependence of the ICR on the AMF intensity at a given SMF. The objects were placed along the axis of the coil which generates the AMF. Unfortunately, it is more difficult to use the tomographic principle for such researches. The ratio of the AMF intensity to the SMF intensity must be varied over rather wide limits in the working volume. This results in the appearance in the working volume of the AMF component orthogonal to the SMP, whose value depends on the co-ordinates. Such situation is extremely undesirable and that led to some critical remarks (for example, /16/). The use of the approach, similar to the tomographic principle, in usual magnetic systems for investigating the dependence of the ICR on SMF will result in a number of inconveniences too. The surfaces of the SMF isointensities are not planes any more. In addition if the SMF value changes, the value of the gradient will change accordingly.

On the basis of the tomographic principle it is possible to develop special medical devices making use of the SMF-AMF synergy effects (for example, the ICR) for treatment at high spatial localisation of the action, limited by a chosen area or areas. In our opinion, it could open some additional prospects for medical practice.

With the use of the tomographic principle a device for the laboratory research on the physical-chemical and biological model objects (fig.1) has been developed by D.B.Diatroptov, L.B.Lugansky and myself / 23 /.

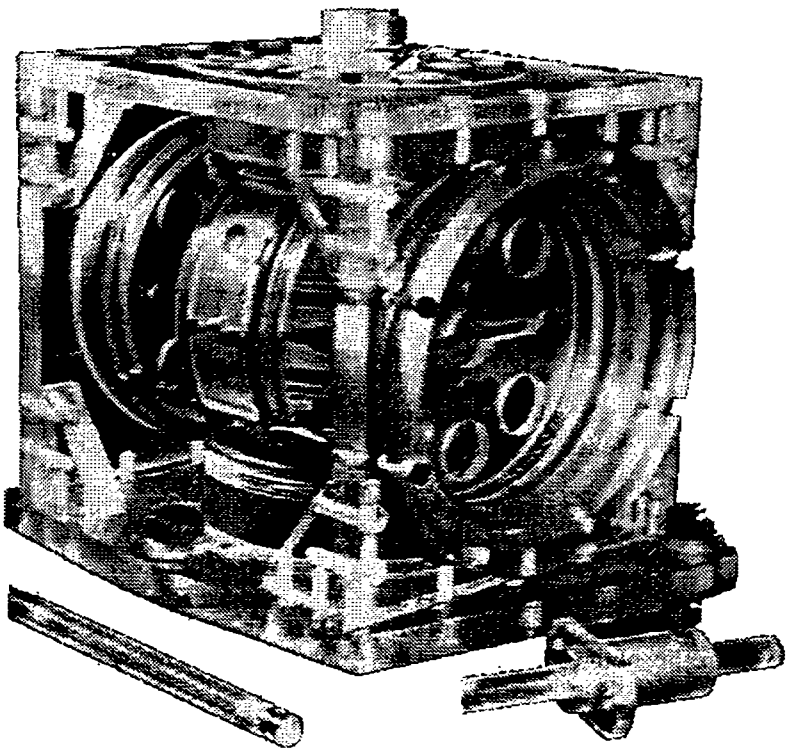

Fig.1 Photograph of the device for studying the SMF and AMF synergy by using the tomographic principle

The SMF, the AMF and the gradients of the SMF are generated in two mutually perpendicular directions - vertical and horizontal, by two systems of coils. The one system is inserted into the other. The diameter of the working

volume is 10 cm. The SMF intensity can vary from zero up to 3 mT (the maximum field corresponds to the frequency of the first harmonic Ca^{2+} about 2.5 kHz), the AMF intensity can vary from zero up to 2 mT. The uniformity - is not worse than 0,1 %. The SMF gradient can reach 0.1 mT/cm.

A little stand for samples can be moved along the axis of the system and be rotated around it with the help of a roller protruding outside. A power control device makes it possible to adjust the currents in the coils separately. Provision has been made for the action of not only the sine wave of the AMF, but also of triangular or the square ones in the range of the frequencies 10^{-2} - $3*10^{3}$ Hz. The forms of the AMF may be also set with the help of external sources of control signals (for example, synthesisers). At a shift of the phases of the sine wave currents in the coils a rotating MF is generated. At a shift of the phases of the square wave currents a field is generated, which is rotated by "jumps".

The possibilities of a partial compensation and a subtraction of the action of the induced currents by the creation of the antiphase electrical field in the working volume have been looked into. By switching the directions of the currents in the coils according to a technique, proposed by A.N. Kuznetzov and B.S.Abdulov /24/, it is possible to obtain background results in the presence of currents in the system.

Experiments with model systems have begun. Yet the statistics is insufficient for discussion of the results.

Two remarks concerning the questions, which fall a little outside the framework of this meeting.

The first remark concerns the necessity of further researches of the possible biological role of vector-potential (VP) of EMF. As is known, the discussion of a physical reality of the VP was begun by D.Bohm and Y.Aaronov.

The possible role of Aaronov-Bohm effect and the VP in biological MF action, in particular, with a reference to the problem of the possible influence of the cosmic VP sources (the poloidal and toroidal MF of the Earth, the Sun and etc.) on the biosphere was discussed in our articles / 25-27/. This influence can be considered «informational» because the classical VP is force-free.

The cosmological VP plays the role of the fundamental vector constant in the theory of the physical vacuum which has been developed by Yu.A.Baurov and Yu.N.Babaev. This theory predicts VP interaction, in which the forces arise. It

allows to explain a large circle of the phenomena observable in the outer space and finds a certain confirmation in the experiments /28 -31 /.

Some questions with reference to the possible biological role of the VP was considered in our joint publications / 29, 30 /. C.W.Smith has shown experimentally, though by using non-classical techniques, that the biological action of the VP really takes place (for example, /31/).

At the moment we have prepared experiments, which will probably allow to clarify some questions.

The second remark concerns the phenomenon of a polycondensation of molecules of polar amino acids in aqueous solutions at exposure to the combined action of the SMF, the AMF and the electric field (EF) discovered by V.V.Novikov (V.V.Novikov and A.S.Lisitzin /32/). The authors consider this phenomenon as a possible mechanism of the biological action of the weak EMF in the biosphere and note that the basic parameters of the experimental model are close to the parameters of a disturbed GMF. From our point of view, these parameters, in some sense are probably close also to conditions on the ancient Earth. This might put a new light on the role of the MF (including the GMF) and the EF in the self-organisation and evolution of molecules and in the construction of more complex molecular blocks.

In the final analysis, it is possible to assert that at the moment the problem of effects of synergy of the SMF and the AMF (and, generally speaking, the EF) has advanced both in terms of the accumulation of reliable experimental data and in terms of the theoretical explanations of possible mechanisms, responsible for this phenomenon. However, new basic questions emerge, which require further serious experimental and theoretical researches. Their results will have great fundamental and applied significance. The latter - both in terms of the problem of electromagnetic safety of humans, as well as in terms of further use of the EMF for diagnostics and for improvement of health status and treatment without medication.

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DISEASES INDUCED BY STATIC MAGNETIC FIELDS. OCCUPATIONAL EXPOSURE RISK CRITERIA

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Modern power-intensive technologies based on the use of direct current (the processes of electrolysis, electromagnetic isotope separation) are connected with the distribution of static magnetic fields (SMF) in a comparatively large volume of the working space and their influence on the health of the technical personnel. The available data on the results of examination of those occupationally exposed to SMF influence (processes of electrolysis), reveal diverse health disorders - insignificant haematological changes (Marsh J.1982), increased risk of leukaemias (Milham S, 1982), some increase in leukaemia mortality, a statistically unreliable risk of development of other kinds of cancer (Rockette H, Arena V, 1983). The mentioned data are one-sided in character and do not reflect the entire picture of SMF influence on the human body. In the cases where only the technological process is indicated and no information is given on the particular hygienic situation in production and, especially, no characteristics of the exposure factor are available, they have a relative value only. Thus the question of a possible participation of the circulatory system in SMF influence and of an estimation of the degree of risk of haematological diseases in those occupationally exposed to this factor, needs validation. As a real model for research of SMF influence on humans, the personnel servicing calutrons, powerful electromagnetic installations, used for the electromagnetic method of isotope division is taken. Maintenance of necessary modes of operation of power and vacuum equipment, control of technological process of isotopes division are the tasks of the personnel. While carrying out this work the personnel is directly at a contour of the technological installation and is exposed to SMF influence (total time of influence of the field on the personnel is 2-4 hours during a working day). Measurements have shown, that inside a working zone, SMF have an expressed non-uniform character; within 2,5 m from the contour of the installation a downturn of the induction from 0.175T down to zero is marked. The sample selection includes materials of the medical examination of 85 subjects. In analysing the materials a package of the statistical programs was used, they were processed on an IBM PC, weight factors were calculated. An analysis of individual data has shown that the signs of SMF influence are found as early as the first years of work. They testify to a vegetative-vascular instability. With the increase in the subjects' length of service from 1 year to 15 years, the percentage of those with vegetative- vascular system instability increases (Pearson's factor 0.65-0.75), and in the surveyed sample there are persons with sharply expressed reactivity (hyper-responsive) to SMF influence manifested in the form of arterial

hypertension (with increase of arterial pressure level up to 180/100 mm of mercury column) or collapses. It was simultaneously established, that the duration of influence of the fields during a working day (total maximum time of contact with SMF 2,3,4 hours) or the sex structure of the sample do not influence the specific weight index of the subjects with vegetative-vascular instability. Rheoencephalography data from standard assignments revealed, that those with long-tern occupational exposures to SMF influence (7-15 years) show deviations from the criterion values of registered parameters (rheographical index 1.5-1.8; coefficient of tonic pressure 1.2-1.3), which reflects a change in the vegetative regulation of the vascular tone and circulation of the blood in the brain. A misbalance of ions of potassium, calcium, sodium in the blood was found in all those exposed to SMF influence, however, it was only in the operators with a long service that these changes fell outside the limits of SI norm in 62-83 of the indicators. The condition of the peripheral blood was investigated in 35 males aged 20-55 with various lengths of service as technical personnel servicing calutrons for 1-35 years. The subjects with chronic somatic diseases, traumas and diseases of CNS with persistent consequences, were not included. While estimating the status of the peripheral blood we used the SI specifications for various forms of leukocytes. The parameters of leukocyte condition were also estimated on the basis of the entropy criterion according to the formula:

$$I=\sqrt{\sum_{i=1}^{\sigma}\left(\frac{A_{i\,max}+A_{i\,min}-2A_i}{A_{i\,max}-A_{i\,min}}\right)^2},$$

where I - integral index of entropy;

$A_{i\,max}$, $A_{i\,min}$ - max, min leukocytes limits by SI;

A_i - real quantity of leukocytes.

The criterion is scaled in such a manner that the values from 0 up to 1 correspond to the norm, deviation from the norm in even one of the elements results in the criterion exceeding 1.

The data calculated according to the above-mentioned formula for the personnel of the calutrons are within the quantity 1,17 - 5,02 limits.

It is of interest to establish, on the basis of the available data, the validity of the opinion that with the increase of the length of work under SMF exposure the system of leukocytes tends to maximum entropy, and also to establish the rate of this growth. The value of the double correlative coefficient is 0.592, which at the

confident probability level of 95% points to the importance of the length of service for the status of the peripheral blood. A regression analysis of the data obtained characterised by the value of integral index dependent on the period of exposure is illustrated by the following formula: $Y=1.19 + 0.065X$, where Y are values of the criterion, X - period of work in a job (period of SMF influence in years). It is evident, that at 1 year the entropy criterion exceeds the norm, and with the increase in the length of service it steadily grows, which, according to the existing criteria, corresponds to the reactions of chronic stress. The integral index of entropy has the highest informativity (SMF influence), characterises the entire inspected group as conditionally specific. For the initial stage the manifestations of instability of the regulating system of blood circulation, with a tendency to arterial hypertension and collapses, are highly informative. Persistent changes in the circulatory system regulation, changes of the contents of ions in blood gain importance for an expressed stage of SMF exposure.

INFLUENCE OF STATIC MAGNETIC FIELDS OF DIFFERENT BIOTROPIC PARAMETERS ON THE MORPHOFUNCTIONAL CONDITION OF ADRENAL CORTEX

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The most important problem of our time is protection of the environment and prevention of consequences of disadvantageous influence of the anthropogenic factors of physical, chemical and biological nature on human health. Among multiple factors of the environment, including those which accompanied the evolution of bio-objects, physical factors of different nature and particularly electromagnetic fields acquire an ever-greater importance.

With the development of science, industry and technology an ever-increasing influence on humans is exercised by artificial magnetic fields (MF), which by several orders of magnitude exceed the geomagnetic field induction. The influence of these fields, as different studies by a number of authors have shown, is not indifferent for the human body; thus the development of investigations on MF biological influence has become a social order (U.A.Cholodov, 1989, 1991; U.P.Siromjatnicov, 1993; V.G.Podkovkin, 1994).

The importance of the endocrine system is well known for the maintenance of homeostasis in different environmental conditions and with pathological processes in the body. A major part of the investigations is devoted to the study of the function of the adrenals and a much smaller one - to their morphology.

The main aim of our work was an experimental study based on comprehensive methods approach with mathematical modelling of the action of a static magnetic field (SMF) with different biotropic parameters on the morphofunctional status of the adrenal cortex.

Modelling of the physical factor was done by making a device to act upon biological objects which made it possible to obtain a great volume of a maximally uniform magnetic field due to an SMF concentration system which consisted of three sections of a certain configuration (patent No 1553141, 1989). The subjects of the study were white rats of no particular breed, for which a special chamber was set up. The chamber promoted the accuracy of the studies by reducing the stress loads (patent No 1664208, 1991).

The animals were subjected to an all-out action by horizontal SMF. The choice of intensities of SMF for studying its influence on the morpho-functional condition of the adrenal cortex was as follows:

10 mT - normalised SMF intensity at working places of different production specialists;

15 mT - SMF intensity often met at working places in production, and also used for physiatric magnetic procedures;

30 mT - high intensity, more than three times in excess of the MPL. Such a value can be encountered at working places of specialists who perform a number of tuning and calibration works while assembling SMF sources;

60 mT - exceedingly high SMF intensity assumed to be close to the values in extreme situations during operation and servicing of the facilities using prospective technologies in different industries.

The choice of the duration of the experiments was conditioned by the following reasons: 30-time SMF action makes up $1/30^{th}$ part of the life expectancy of white rats; if extrapolated to humans it would be approximately equal to 2.5 years of human production activity. This period corresponds to the duration of work of a number of specialists.

90-time SMF action corresponds to a chronic experiment. The duration of exposure to this physical factor corresponds to 10% of the life expectancy of white rats; if extrapolated to humans it would be equal to 7-7.5 years of human production activity.

As material for the studies we took the adrenal glands whose morphofunctional condition was evaluated by common morphological, morphometric and hystochemical methods. The multivariate quantitative features obtained were processed by means of the system multifactorial analysis, with the calculation of integral indicators upon the results of which were built mathematical models, reflecting the nature, expression, dynamics, directivity of the developing processes and the length of the reconstruction period. The influence factors, determined and situated within the increasing gradations, made it possible to detect the most informative indexes of the subjects under study exposed to SMF.

As a result of the studies conducted (total duration 180 days) changes were discovered in the morphofunctional condition of the adrenal cortex in response to

SMF exposure at MPL (magnetic induction value 10 mT, exposure 4 hours). The influence of normalised (10 mT) SMF brought to an increase in the width of the adrenal cortex width, the maximum increase of the indicator occurring on day 60 of the experiment. Morphologically, in the preparations of this period we observed an expansion of the capillaries between epitheliocities and oedema of tissue. After cancelling the influence of the factor, on day 120 of the study, the width of the adrenal cortex was significantly increased which was indicative of an expressed hypertrophy of the organs' cortical material. On days 150 and 180 of the experiment the indicator under study did not differ from the norm.

We observed that each area of the adrenal cortex responded differently to the SMF influence at MPL.

Changes in the width of the fascicle area of the adrenal cortex were more pronounced as compared to the glomerular and reticular areas, and the increase or indicator continued in the period of after-effects.

We established that the chronic normalised SMF influence substantially affected the morphometric characteristics of the adrenal cortex cells. As a rule, the action of the factors resulted in the increase of the volume of cells, nuclei and nucleoli in all the areas of the adrenal cortex.

Major indicators in the evaluation of the morphofunctional condition of the adrenal cortex were the correlations between cytoplasm and nucleus (CNC), cytoplasm and nucleolus (CNsC), nucleus and nucleolus (NNsC). Intracellular factors changed under the action of normalised SMF; in the period of after-effects a trend towards normalisation was noted on days 150 and 180 of the study.

It is known that ascorbic acid (AA) takes part in the syntheses of corticosteroid hormones, its amount in the cells of the adrenal cortex is determined by their functional activity. For hystochemical detection of AA a method, proposed by Giroux and Leblon was used with the modifications by H.H.Neprjahin and V.P.Nefedova.

AA was found in the form of black grains unequal in size. Because of the different amount of grains in cells and as a matter of convenience for quantitative evaluation we classified the cells into three types according to the presence and amount of AA in them. In the cells of the first type AA was absent. In the cells of the second type single small granules were found. The third type was characterised by multiple grains and the presence of medium and large grains. In all events of chronic normalised SMF influence we observed an increase in the number of cells

of the second and third types and a reduction of the first type cells. Such changes were indicative of the increase in AA content in all the areas of the adrenal cortex and of the activation of their functioning. After the factor ceased to act, these changes returned to the norm and thereupon fluctuated within its confidential borders.

Considering the interrelation between the morphometric characteristics of cells and the processes developing in cell structures and secured by enzyme systems, we defined such ferments as succinic dehydrogenase (SDH) and lactate dehydrogenase (LDH) on a one-beam cytospectrophotometer upon their absorbance in conditional units. Under the action of the normalised SMF in all (particularly fascicle) areas, we revealed a reduction in the SDH activity. LDH activity in cells of all the areas of the adrenal cortex under the normalised SMF displayed an upward trend with subsequent normalisation of the indicator under study when the action ceased.

A comprehensive evaluation of the nature and directivity of the developing processes was made possible by the use of the system multifactorial analysis, which, on the basis of the deviation of integral factors, allowed finding the degree of morphofunctional change. An analysis of the mathematical models pointed to the oscillatory nature of the processes occurring in the organ. The most prominent changes under SMF influence were seen days 60 and 90 of the experiment. In the period of after-effects on days 120 and 150 we observed a trend towards normalisation of the morphofunctional condition of the adrenal cortex. The weight factors studied have shown that the most influential factors acting upon the mophofunctional condition of the adrenal cortex under normalised SMF were: width of area, volume of cells, activity of SDH and LDH.

As a result of the studies conducted, it was revealed that a 30-day exposure to SMF of different biotropic parameters resulted in changes of the width of the adrenal cortex which reflected the adrenals' morphofunctional condition. A significant reduction of the indicator under study was noted from the first day of SMF exposure with the magnetic induction of 60 mT.

Morphologically, in the preparations of this period we observed vacuolar dystrophy and destruction of single epitheliocytes, in some cells were observed mitoses, found vascular changes; haemostasis phenomena occurred among epitheliocytes. We noted substantial changes in the morphometric indicators expressed through changes in the width of the area, the volume of cells, nuclei, nucleoli, as well as intracellular structures (CNC, CNsC, NNsC) in all the areas.

Changes were observed in the hystochemical indicators of the adrenal cortex under a 30-day exposure to SMF of different biotropic parameters, and those were most pronounced in the 60 mT series.

According to the data of mathematical models, in all the areas of the adrenal cortex a deviation of the integral factor was revealed during the period of SMF exposure. By the end of the study the integral factor did not return to the normal value, while the degree of deviation and a trend towards further growth was revealed in the fascicle area under exposure to SMF with the value of magnetic induction of 60 mT.

On the basis of the weight factors analysis it was revealed that the greatest impact upon the morphofunctional condition of the adrenal cortex under a 30-day SMF exposure was exerted by: width of the area, volume of cells, CNC, activity of SDH and LDH.

On the whole the studies conducted have allowed drawing the following conclusions:

1. A static magnetic field as a physical factor of the environment, possessing a biological action, causes a change in the morphofunctional condition of the adrenal cortex, with the degree of expression dependent on the values of magnetic induction and exposures to the factor.

2. Chronic (90-day) exposure to normalised (10 mT) SMF caused reversible morphological changes in all the areas of the adrenal cortex, which were expressed in the expansion of capillaries, tissue oedemas, vacuolar dystrophy, increased volumes of cells and nuclei, changes in the relations of intracellular structures, increased AA content in cells, reduction of SDH activity and increase in LDH activity.

3. A small deviation of the integral indicator in the mathematical models during the normalised SMF exposure and its early approximation to the norm after the action is over reflected a reactive nature of the processes developing in the adrenal cortex, while the absence of destructive changes and of the influences on genetically important structures (stability of nucleoli volume factors, NNsC) testified to the absence of damaging SMF action at MPL on the organ.

4. Under a 30-day SMF exposure at the intensity of 15 mT (exposure duration 4 hours) and at 30 mT (2 hours) the following was revealed during the

influence of factor: increased width of the adrenal cortex and each of its areas, of cell volumes, nuclei, nucleoli, changed correlation of the intracellular indicators, increased AA content, increased LDH activity along with reduced SDH activity, with subsequent normalisation of the indicators under study on days 20 and 30 in the period of after-effects.

5. According to the data of the mathematical models, the 15 mT SMF causes the most pronounced changes in the morphofunctional condition of the adrenal cortex on day 30 of the exposure with subsequent approximation of the integral indicator to the normal value in the period of after-effects, which, in combination with the morphological, morphometric and hystochemical data, reflected, on the whole, the reactive nature of the process.

6. Under the 30 mT SMF exposure (exposure duration 2 hours), the mathematical models showed a more significant deviation of the integral indicators during the exposure, with no return to the initial level up to day 60 of the study in the glomerular and reticular areas, and the combination with the discovered (both reactive and dystrophic) processes was indicative of more significant changes in the morphofunctional status of the adrenal cortex.

7. The 60 mT SMF exposure for 1 hour caused pronounced dystrophic-destructive changes in the adrenal cortex manifesting themselves in the thinning of the cortex in each area, reduction in the volume of cells, nuclei, nucleoli, changes of CNC, NNsC, presence of vacuolar dystrophy, destruction of epitheliocytes, reduction of the AA amount and of the activity of SDH, LDH, with the changes increasing in the period of after-effects.

8. A significant deviation of the indicator in the mathematical models during 60 mT SMF exposure for 1 hour and the trend towards its further increase in the period of after-effects, particularly in the fascicle area, was indicative of the unfavourable nature of influence of the physical factor with such biotropic parameters.

9. The magnitude of the influence factors was used to determine the indicators most influencing the morphofunctional condition of the adrenal cortex under exposure to SMF of different biotropic parameters, which were: width of area, volume of cells, CNC, activity of SDH and LDH. These indicators can be used for the evaluation of the morphofunctional status of the adrenal cortex in the medico-biological studies.

STATIC MAGNETIC FIELD MODIFIES THE FREQUENCY-DEPENDENT EFFECT OF THE EHF EMR ON IMMUNE SYSTEM CELLS

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1. INTRODUCTION

By now a great amount of experimental data has been accumulated, showing the effective influence of electromagnetic radiation of extremely high frequencies (EHF EMR) on biological systems of various levels of organisation [Devyatkov et al, 1991; Grundler et al, 1992]. The interest in biological effects of electromagnetic fields (EMFs) and EMR is determined by several circumstances. Firstly, the definition of scientifically justified safe norms for the population and technical staff, working at facilities generating EMR, is necessary [Akoev, 1983], forasmuch as the number of EMF sources of anthropogenic origin is rapidly increased, and the body is affected by complicated combined static magnetic fields (SMFs) and EMFs of different nature. Secondly, in recent years the methods of electromagnetic therapy are being actively introduced into medical practice for treatment of different diseases [Andreev et al, 1985; Digests of papers, N.D.Devyatkov (ed.), 1987, 1989]. However, the medical application of the methods is based on empirically obtained effects and is not supported by solid knowledge of specific biophysical mechanisms. The problem of physico-chemical mechanisms of the EMF influence on cells and organisms as a whole remains open.

Another problem in the investigation of mechanisms of the EMF influence on biological systems is weak reproducibility of the results of some investigations, that leads to insecurity in the evaluation of these results and, as a corollary, to their wrong interpretation. Many authors note, that such a situation is caused by inaccurate observance of and incorrect hardware for the experimental conditions [Bryukhova et al, 1985; Furia et al, 1986; Gos et al, 1997]. Therefore, the creation and monitoring of optimum experimental conditions are the directions, in which investigations of the influence of weak EMFs on cellular level are carried out. The analysis of stability and reproducibility of biological effects of the EHF EMR leads to the assumption that the magnitude, direction and frequency characteristics of the effects can depend on magnetic induction of the SMF, at which exposure of the objects is carried out.

Formerly we showed, that continuous EHF EMR (41.75-42.15 GHz) of low intensity (250 $\mu W/cm^2$) inhibited resonantly the production of reactive oxygen species (ROS) by neutrophils, activated by opsonized zymosan [Gapeyev et al, 1996]. At exposure of the neutrophils in the near-field zone of the channel radiator the maximum inhibition of luminol-dependent chemiluminescence by 25% was observed at the radiation frequency of 41.95 GHz. From the literature it is known, that EMFs can have an expressed immuno-modulating effect and substantially transform the functional status of the elements of the immune system. Frequency-dependent inhibition of the initially increased NBT-test in monocytes and neutrophils was shown [Khomenko et al, 1995]. The EHF EMR (61.22 GHz) reduced the toxic effects of cyclophosphamide on cellular immunity of mice as observed by the increased phagocytic activity of peritoneal macrophages and enhancement of T-cells proliferation [Rojavin et al, 1997]. At the influence of low-frequency (60 Hz) magnetic field (0.1 mT) on rat peritoneal neutrophils the increase of the ROS synthesis was found at phorbol ester (PMA)-induced respiratory burst [Roy et al, 1995]. To explain the effect obtained the authors of that work make use of the hypothesis on a possible reduction of the rate of radical pair recombination under the action of a magnetic field, which leads to an increase in the overall concentration of free radicals [Eichwald and Walleczek, 1996]. Cytotoxic properties of phagocytes (neutrophils and macrophages) is determined by their ability to synthesise ROS at the respiratory burst induction. Possible influence of the SMF on the lifetime of free radicals and/or on the activity of Ca^{2+}-dependent enzymes of involved intracellular signalling systems can change the neutrophil respiratory burst intensity, and, consequently, modulate the effect of external factors, for example, such as the EHF EMR.

The objective of the present work was checking up of a potentialities of modification of the effects of continuous EHF EMR on immune system cells at various value of magnetic induction of the SMF, and determination of a role of the geomagnetic field in frequency dependencies of the effects.

2.Materials and Methods

Cell preparation. The work was performed with evoked peritoneal neutrophils of SPF-category mice of outbreeding line NMRI. The mice were obtained from a barrier type vivarium of the Laboratory of Linear Animals of a branch of M.M.Shemyakin and Yu.A.Ovchinnikov Institute of Bio-organic Chemistry. The mean weight of the experimental animals was 25-30 g. The following materials and solutions were used: zymosan, luminol, phorbol 12-myristate 13-acetate (PMA), calcium ionophore A23187, medium 199 and Hanks' solution were obtained from Sigma Chemical Co. (USA). For luminol-dependent

chemiluminescence (CL-L) measuring the test solution contained 138 mM NaCl, 6 mM KCl, 1 mM $MgSO_4$, 1 mM Na_2HPO_4, 5 mM $NaHCO_3$, 5.5 mM glucose, 1 mM $CaCl_2$, and 350 mM luminol, were buffered at pH 7.4 with 10 mM HEPES/NaOH. The peritoneal neutrophils were isolated according to the procedure described in [Gapeyev et al, 1996] with some modifications. The isolated cells were re-suspended in medium 199 and kept at 4°C with interfusion. The neutrophils in the suspension formed more than 80% of all cells. The suspension was further diluted with test solution in cuvettes immediately prior to experiment (20 ml of the cell suspension per cuvette with a total working volume of 200 ml). The concentration of the neutrophils in the cuvettes was about 10^6 cells/ml. After inserting into cuvettes the cells were spontaneously attached to the cuvette bottom for about some minutes and represented a monolayer with a thickness less than 0.1 mm. The height of the solution in the cuvette was about 2 mm.

SMF and EHF EMR design. The SMF was created by two pairs of Helmholtz coils 40 cm in diameter, which were supplied by controllable stabilised current sources. With the help of these coils a static magnetic flux in their centre was ensured. The value of magnetic induction was measured with a ferromagnetic probe magnetometer with an accuracy of at least ± 0.1 μT. The system of Helmholtz coils was set up coaxially with the horizontal component of the Earth's field and did not contain materials, distorting a magnetic field. The value of magnetic induction was set at about 50 μT (horizontal and vertical components were 26, and 42 μT, respectively), close to the average background value of the geomagnetic field in our laboratory conditions, and 100 μT (raised twice).

To irradiate the neutrophils a wide-band radiator of millimetre waves with an aperture of 17.5x12.5 mm based on the channel waveguide (further «the channel radiator»), developed by PIRS (Special Design Bureau of Information Technologies, Russia), was connected with a high-frequency generator of signals G4-141 (USSR). The frequency range and frequency stability of the generator were 37.5-53.5 GHz, and ±0.05%, respectively. A parasitic frequency deviation of the output signal in the continuous generation mode was not more than 6 MHz. The output wave frequency was controlled by a CH2-25 wavemeter. The maximum output power of the generator measured with an M5-49 thermistor head was about 40 mW. The spatial distribution and the estimation of the energy flux density (EFD) of the radiation in the far-field zone of the channel radiator at a distance of 400 mm from its radiating end were determined using an R2-68 panorama measuring unit. Taking into account the skin depth of 0.78-0.23 mm for biological media in the frequency range of 30-300 GHz [Furia et al, 1986], estimating EFD and specific absorption rate in a thin solution layer of about 0.1-0.2 mm we obtained an absorbed energy flux density (AEFD), corresponding to the absorption

of the radiation by the solution layer with the cells. The calculated value of the AEFD at the distance of 400 mm from the radiating end of the radiator was about 100 mW/cm^2 at the maximum output power of the generator [Gapeyev et al, 1996].

The experimental plastic cuvettes (diameter 10 mm, thickness of walls and bottom 0.2-0.3 mm) with the cells were fixed in a holder made of diamagnetic materials, so that the square of the space, occupied by the cuvettes, did not exceed the area of a homogeneous magnetic flux, created by Helmholtz coils. The cells were irradiated at a room temperature of 19-22°C from the side of cuvette bottoms in the far-field zone of the channel radiator (at the distance of 400 mm from its radiating end). Six cuvettes out of twelve used in one experiment were shielded from the EHF EMR by a special multilayer shield, not distorting the SMF and excluding an increase in the heterogeneity of the EMF in the near zone of irradiated cuvettes. The influence of the SMF with assigned value of magnetic induction and the EHF EMR was executed during 20 min in the presence of calcium ionophore A23187 (7.5-10 μM). As a control we used shielded six cuvettes with the cells, also treated by calcium ionophore A23187 for 20 min. A false exposure (sham-control) was carried out in similar conditions when all devices were switched on, but the output power of the high-frequency generator was absent. After the influence of the SMF and the EHF EMR or the false exposure the experimental and control cuvettes were placed into a chemiluminometer for a measurement of the CL-L.

Measurement and analysis of the CL-L. The ROS production by the neutrophils activated by PMA was estimated by the CL-L, measured by the known technique [Vladimirov & Sherstnev, 1989]. The CL-L was registered by the chemiluminometer CL111-4, constructed at the Laboratory of Nerve Cell Biophysics of Institute of Cell Biophysics of Russian Academy of Sciences. The chemiluminometer design allowed us to record the CL-L in series from 12 experimental cuvettes at 37°C. The interrogation time of all 12 cuvettes was 10 s. The signal from the chemiluminometer was transferred to a personal computer. Further analysis was carried out using the special programs, developed in Turbo Pascal 7.0. During first 3 min we recorded the CL-L intensity of non-activated cells (spontaneous CL-L), then PMA (1μM) was added and the recording of the CL-L level of the activated neutrophils was continued for the necessary time. The total ROS production by the neutrophils for 5 min was evaluated proportionally to the square under the progress curve of the CL-L intensity. The mean spontaneous CL-L intensity and the moment of PMA addition were taken as zero, and origin of time, respectively. For further analysis the total ROS productions were averaged for the control and irradiated neutrophils, and the difference of the control from the irradiated cells was evaluated as the difference of the ROS production by the

control and irradiated cells, normalised to the control and expressed in percent. If, for example, the total ROS production by the control cells surpassed that by the irradiated cells, we obtained a positive percentage value, which reflected the degree of inhibition of the CL-L of the neutrophils as the EHF EMR effect. Statistical analysis of the data was based on the Student t-test. The reliability of the results was estimated according to the boundaries of the confidence interval with the probability $p > 0.95$.

3.Results

Joint action of two agents - calcium ionophore A23187, raising intracellular free calcium concentration ($[Ca^{2+}]_i$) [Campbell & Hallet, 1983], and phorbol ester PMA, activating protein kinase C (PKC), passing over receptor-dependent pathways [Badwey & Karnovsky, 1986; Nishizuka, 1992] - at the neutrophil respiratory burst activation results in a significant (2-5 times) enhancement of the cell response in comparison with the neutrophil activation at the action of each these agents separately. Namely, the enhancement of the ROS production by the neutrophils at the joint action of calcium ionophore and PMA proceeds in a non-additive manner and synergistic effect is observed [Safronova et al, 1997]. In our experiments we used a model of the synergistic reaction of A23187 and PMA in the neutrophil respiratory burst activation to investigate the SMF and the EHF EMR effects. Formerly we showed, that the effect of continuous EHF EMR on the synergistic reaction had a non-linear dependence on the concentration of calcium ionophore A23187. Within the range of low A23187 concentrations (0.1-5 μM) the EHF EMR effect did not observed and was exhibited only at high ionophore concentrations (5-20 μM) [Safronova et al, 1997]. So, at A23187 concentration of 5 μM we observed inhibition of the CL-L of the neutrophils by about 25% from the control, the effect was increased with increasing of A23187 concentration and at concentration of 20 μM made about 50%. We have chosen the range of A23187 concentrations from 7.5 to 10 μM, at which the reliable inhibition of the synergistic reaction was observed on exposure to the EHF EMR with frequency of 41.95 GHz. On Fig.1 the original records of the CL-L intensity of the neutrophils are shown under different conditions of the cell activation. Synergism in the action of A23187 and PMA is seen at comparison of curves 1 and 2, corresponding to the action of PMA alone and to joint action of A23187 and PMA in respiratory burst activation. The curves 3 and 4 (Fig.1) show a modification of the CL-L of the neutrophils at values of magnetic induction of the SMF 50 and 100 μT and frequencies of the EHF EMR 41.95 and 42.0 GHz, respectively. The original records are shown for the radiation frequencies, at which the maximum effects were found (inhibition by about 24% at the frequency of 41.95 GHz and activation by about 24% at the frequency of 42.0 GHz).

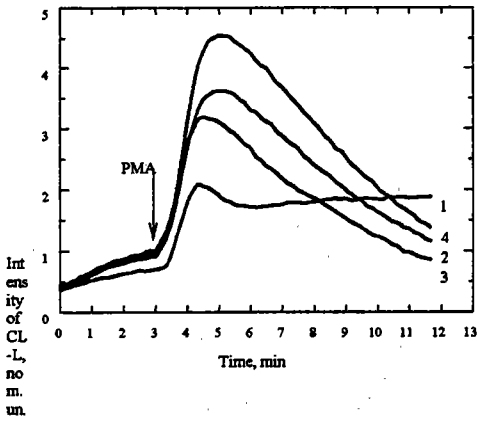

Fig.1. Original records of luminol-dependent chemiluminescence intensity of the neutrophils activated by PMA (1 μM was added in 3 min after beginning of the registration): 1 - the intact cells; 2, 3 and 4 - the cells pre-treated by A23187 (7.5 μM). 1 and 2 - non-irradiated cells. Irradiated cells (continuous generation, AEFD was about 50 $\mu W/cm^2$): 3 - at frequency of 41.95 GHz and value of magnetic induction of the SMF 50 μT, and 4 - at frequency of 42.0 GHz and value of magnetic induction of the SMF 100 μT.

To investigate frequency dependencies of the EHF EMR effects on the synergistic reaction in the neutrophils at various values of magnetic induction of the SMF we have carried out two series of experiments. Magnetic induction of the SMF was set at about 50 or 100 μT, frequency of the EHF EMR was changed within the limits of 41.85-42.1 GHz with a step of 50 MHz, the AEFD of the radiation in all experiments was about 50 $\mu W/cm^2$. The influence of the EHF EMR on the neutrophils at a value of magnetic induction of the SMF of about 50 μT caused resonance inhibition of the synergistic reaction, with a maximum decreasing of the ROS production by 24% from the control being at the frequency of 41.95 GHz, as it was shown recently [Gapeyev et al, 1997]. Under the influence

of the EHF EMR with the same frequency range, but at a value of magnetic induction of the SMF of about 100 μT, resonance activation of the synergistic reaction was found with the maximum increase of the ROS production by 24% from the control at the radiation frequency of 42.0 GHz (Fig.2). The analysis of the results, shown on Figure 2, pays attention to the fact, that in the EHF EMR effects to the synergistic reaction there are two components of modification of the CL-L of the neutrophils - one not dependent on the radiation frequency and the other frequency dependent. A modification of the first component at the used values of magnetic induction of SMF makes no more than 10% from the control. The modification of the second component was found only in narrow bands of the radiation frequencies and makes about 15% (excess above the level of the first component). At a raised SMF (100 μT) the EHF EMR effect for both components does not practically change, however, the direction of the effect changes (instead of inhibition of the synergistic reaction at the SMF of 50 μT, activation is observed), and also resonance frequency of the effect is shifted approximately by 50 MHz. Thus, the obtained results show, that doubling of the value of magnetic induction of the SMF in comparison with the background is capable of changing the neutrophil metabolic status in such a manner that the direction of the EHF EMR effect is reversed and a shift of the effective resonance frequency occurs.

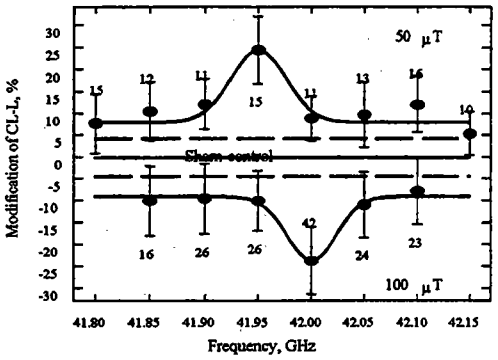

Fig.2. Frequency-dependent modification of the ROS production by the neutrophils, estimated by the CL-L level, on exposure to the EHF EMR at different values of magnetic induction of the SMF: 50 μT (upper curve) and 100 μT (lower curve). In the middle of the Figure the effect ( ) and confidence intervals (- -) of false exposure (sham-control) are shown. Each point represents the mean value and a confidence interval ($p > 0.95$) and the number of independent experiments are indicated.

4. Discussion

Phorbol ester PMA used in our experiments as a test agent for the evaluation of modifications of the metabolic neutrophil status, caused by other factors, is a synthetic analogue of diacylglycerol (DAG) and activates PKC, passing over receptor-dependent pathways [Nishizuka, 1992]. The activated PKC phosphorylates membrane proteins, including cytosolic components of NADPH-oxidase. The PKC activity is interconnected with the metabolism of many second messengers and enzymes of intracellular signalling systems. So, Ca^{2+} ions significantly increase the PKC affinity for DAG, the intensity of phospholipid hydrolysis also changes the degree of PKC activation. There is a negative feedback

from PKC to phospholipase C, ensuring a reduction of PKC activity, and a positive feedback from PKC to phospholipase A_2 (PLA_2) and phospholipase D, ensuring a raising of PKC activity [Nishizuka, 1992]. At a certain level of the neutrophil activation the defined balance of the contribution of considered signalling systems to the PKC activity is reached. External influences can shift this balance extensively, modifying the PKC activity, that at the functional activity level can be reflected in a modification of the ROS production during the respiratory burst. For the analysis of possible mechanisms of modification of the EHF EMR effects on the synergistic reaction of A23187 and PMA in the neutrophil respiratory burst activation at various values of magnetic induction of the SMF the following considerations could be invoked.

The magnetic field can change the rates of transients between singlet and triplet spin states of radical pairs, and, consequently, the average concentration of free radicals can be changed. Due to this mechanism, in the presence of the field a changeover of biochemical reactions, comprising a stage of the radical pair recombination, can occur [Eichwald and Walleczek, 1996]. Thus, the dynamic balance of intracellular signalling systems can be disturbed, and a modification of functional activity occurs. The EMR effects to forming and recombination of radical pairs and possible consequent modification of biological object functioning were considered in works [Grundler et al, 1992; Vax et al, 1994].

In the model for the interaction of weak combined, static and alternating magnetic fields with biological systems (theory of magnetic parametric resonance), proposed by V.V.Lednev [Lednev, 1991; Lednev, 1996], the primary link in the chain of events, triggered by the influence of a weak magnetic field, is the Ca^{2+} ion, specifically bound to the Ca^{2+}-binding centre of protein. The theory shows, that the SMF can modify Ca^{2+} affinity for Ca^{2+}- and Ca^{2+}-calmodulin-dependent enzymes, that does not conflict with the results obtained in experimental works [Lednev et al, 1996; Markov & Pilla, 1997].

At the value of magnetic induction of the SMF, comparable with that of the background geomagnetic field (about 50 μT), the resonance inhibition of the synergistic reaction of calcium ionophore A23187 and phorbol ester PMA under the action of continuous EHF EMR can be stipulated by the influence of the radiation on Ca^{2+}-dependent intracellular signalling systems of the neutrophil. As noted earlier [Safronova et al, 1997; Gapeyev et al, 1997], the effect was found only when Ca^{2+} fluxes through plasma membrane and raised $[Ca^{2+}]_i$ were ensured by high A23187 concentrations. It is possible, that the EHF EMR changes $[Ca^{2+}]_i$ or affinity of key enzymes for Ca^{2+}, thus activating series of Ca^{2+}-dependent enzymes and shifting the balance of intracellular signalling systems, enhancing

positive feedbacks. A result of this is the hyperactivation of the neutrophil and inhibition effect of the radiation at the level of functional activity - the ROS generation during the respiratory burst activation by phorbol ester.

At doubling the value of magnetic induction of the SMF in comparison with the background, the EHF EMR effect was reversed and the resonance frequency of the effect was shifted (Fig.2). It is possible, that in this case the SMF, changing Ca^{2+} affinity for Ca^{2+}- and Ca^{2+}-calmodulin-dependent enzymes (according to the Lednev's model), specifically modifies the activity of a series of key enzymes (PKC, PLA_2), therefore the hyperactivation of the cell during the exposure does not occur (in comparison with the exposure at the background value of the geomagnetic field 50 μT). The EHF EMR against the background of specific modification of enzymes activity, resulted from the SMF, causes changes, which in the consequent test for the neutrophil functional activity at the respiratory burst initiation by PMA are manifested as an activation of the synergistic reaction. Presumably, against the background of a changed neutrophil functional status by the SMF another frequency of the radiation becomes more effective, which explains the small shift of the effect resonance frequency. It is obvious that, to solve the problem of specific physico-chemical mechanisms and targets of the influence of the SMF and the EHF EMR, further investigations are required.

Our results allow assuming, that the targets of the influence of the EHF EMR and the SMF on immune system cells (neutrophils) can coincide. On the basis of our data, we suppose, that within the range of values of magnetic induction of the SMF 50-100 μT there are such values, at which the EHF EMR effect to the synergistic reaction of A23187 and PMA will be absent in the same way as with compensated SMF. The results obtained in the work show a strong dependence of the EHF EMR effects on the value of magnetic induction of the SMF, which must be taken into account for the application of electromagnetic therapy methods in medical practice.

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OCCUPATIONAL AND NONOCCUPATIONAL EXPOSURE TO EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS AS A RISK FACTOR

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Evaluation of long term effects of ELF EMF is currently considered in Russia as an important task. Four epidemiological studies have been performed at the Institute of Occupational Medicine of the RAMS to address this problem.

The impact of extremely low frequency EMF on workers' health has been the subject of investigation in the first study. The study covered six 500 kV power substations. All of them are similar: they have been in operation since 1956, and are situated in 5 regions of the central Russia.

Working conditions were evaluated at the «open distribution equipment» territories, and at the working places of the field staff directly engaged in the maintenance of electric lines. It was revealed that the voltage of the electric fields (EF) fluctuated from 0 to 28 kV/m. It should be noted that in Russia the maximum permissible level (MPL) for a full working day exposure is set at 5 kV/m.

The magnitude of the magnetic fields (MF) was in the range from 0.16 to 10.8 A/m.

It should be mentioned that the linesmen servicing electricity transmission lines are exposed to the EF voltage in the range of 15 to 2000 kV/m. However the, use of shielded equipment provided effective protection. MF exposure on the premises of the linesmen is much lower than the MPL for occupational exposure.

Retrospective cohort mortality study was carried out. Linesmen, substation operators, dispatchers, maintenance workers, etc., who had been exposed to EMF for at least one year and who started work between 1 January 1956 and 31 December 1980, were included in the occupational cohort. The follow-up comprised the period from 1970 to 1992. At the end of the period from 1532 cohort members, who contributed 24,000 person-years, 1319 persons were alive, 141 died, and 72 were lost from the follow-up. Cause-specific age standardised mortality rates of the surrounding population were used for comparison. While discussing the results obtained, we will pay greater attention to the male mortality as men accounted for 82% of the cohort.

The structure of the male death causes was similar to that of the Russian male population. Total SMR (reflecting all death causes) was lower than the background rate, being equal to 0.61. The study didn't reveal any excess of either all cancers or of cardiovascular diseases - 0.89 and 0.54 respectively. These data have been interpreted as «a healthy worker effect».

Elevated risk of 2.0 for leukaemia was found in men, however it was not statistically significant (95% C.I. 0.23 - 7.31).

A complementary case-control study in Moscow region has been performed to reveal risk of developing haemoblastosis due to EMF exposure. Cases were represented by 571 haemoblastosis patients diagnosed in the time period 1989 - 1992. Controls were 1208 patients with stomach cancer. Questionnaires were mailed to the subjects and the data obtained enabled us to identify the prevalence of ELF EMF exposure. Stratification analysis for unmatched series helped to take into account not only sex, age, but also other frequency EMF as confounders. OR (Odd Ratio) has been calculated. Data processing resulted in revealing a slightly increased risk for leukaemia in males -1.64. However, OR was statistically insignificant.

Another case-control study was undertaken to assess occupational exposure to ELF EMF of parents as a risk factor for their children developing haemoblastosis. The cases were 208 haemoblastosis patients aged up to 14, Moscow residents, who got the disease between 1990 - 1994. Among them were 132 children with leukaemia and 76 with lymphomas. Controls represented a random sample of 319 children admitted to the accident department of the Moscow region orthopedics hospital in the same period.

Data on socio-demographic, medico-biological, environmental and occupational factor, have been collected. The socio-demographic factors included the parents' age, education, migration (if any), smoking and alcohol consumption, lifestyle, social status. The medico-biological factors were represented by information on pregnancy and delivery, drugs, chronic diseases of the parents before the childbirth, cancer history in the family, etc. The occupational factors included occupational exposure to different EMF frequencies, chemical and biological agents, etc.

Parental and environmental exposure to chemical agents and radionuclides, exposure to other frequency EMF, hereditary problems were considered as confounders.

OR was calculated. Stratification analysis was implemented. OR was revealed at the level of 1.69 but that was statistically insignificant.

Finally, a retrospective cohort study of population residing near electricity transmission equipment was performed to evaluate residential exposure to ELF EMF. A small settlement of Energetik in Vladimir oblast was chosen for this investigation. It was built in 1956 for power substation workers. The migration level is extremely low in the settlement. The bulk of the population lives in the same neighbourhood from birth to death.

A hygienic assessment demonstrated that the EF levels in the settlement did not exceed 1 kV/m, while the MF levels - 0.36 A/m; inside the dwellings the values were 0.5 kV/m and 0.26 A/m, respectively. So, the EF strength at the site adjacent to electric lines in the residential area turned out to be within the allowable level, set for residential zones. It should be mentioned that a lot of people at Energetik have summer dwellings or dachas. These dachas are located just under electric lines. The EF intensity was found to reach 3 kV/m outside and 1.5 kV/m inside the dwellings. They were, thus, 3 times higher than the MPL set for residential zones both outside (1kV/m) and inside (0.5 kV/m).

As for MF, the MPLs for CF MFs are being developed now. The observed levels proved to be much lower than the standards recommended by International Organisations though they were 1 - 2 orders of magnitude higher than the Earth natural magnetic field.

As in the occupational cohort, the cause-specific mortality was considered as a measure of health effects. The follow-up comprised the period from 1 January 1971 to 31 December 1990. All cohort members contributed a total of 50460 person-years at risk (23258 men and 27202 women). The mortality patterns of the exposed cohort was compared to the mortality patterns of the general population of the region.

The SMR of the exposed residents for all death causes as well as for all and specific cancers were not higher than in the general population. SMR for leukaemia was 1.3 for males and females (95%CI 0.2 - 7.0).

In conclusion it should be noted that though slightly increased risks of leukaemia were identified in different studies, statistical insignificance does not allow considering the revealed associations as an evidence for causal relations. However, the revealed tendency, which is in agreement with many foreign

epidemiological studies, should not be ignored. It calls for further research in this area.

SOCIAL AND PSYCHOLOGICAL MONITORING OF EXTRA HIGH-VOLTAGE SUBSTATION AND TRANSMISSION LINE PERSONNEL

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Trends and paces of development of power generation are defined to a large extent by the reliability degree and ecological safety of electrical power systems. Reliability, in turn, is conditioned in many ways by the optimum functioning of the "man-machine" system, as this is understood in ergonomics [1, 2]. The optimum performance of an operator depends not only on the factors of the internal medium (the genetic peculiarities of an individual) but also on the whole set of external effects: working environment, regional (national, global) ecology and social-psychological factors.

Typically any social-psychological and biomedical examination of production workers is based on the following three fundamental positions: an evaluation of the significance of the whole set of physical, chemical and social-psychological factors, a system of protection and prevention as well as on rehabilitation and (if required) treatment. A special place in the psychology of risk belongs to the role of exaggerated human perception of the risk levels of the environment and production. This is, in many respects, determined by the knowledge (or incomplete knowledge) spread by mass media on the biomedical effects concerning not only ionising radiation but electromagnetic fields (EMF) as well. Contradictory epidemiological observations of the unfavourable effect of low frequency EMF on humans do periodically appear [3]. Among other things in particular the carcinogenic effect findings are also contradictory [4, 5]. These facts cannot pass undetected not only by mass media but also by the personnel of power network units as well as by the members of their families living near EMF sources. All this creates an unfavourable background for the perception of the environmental and occupational EMF effects by the society.

The occupational reliability of power systems personnel is influenced by not only physical, chemical, and social factors but, in recent years, also by political and religious considerations. These latter may be dominant. So, the evaluation of not only the somatic health status of workers, but also of their social-psychological portrait, presents a very important problem.

The social-and-psychological examination of Power Systems personnel was conducted within the framework of the biomedical and ecological programs «EES Russia» (RAO «UPG of Russia»). In particular, these studies were conducted at the high-voltage substation (500 kV and 750 kV) «Belyi Rast». An integrated ecological evaluation of: the levels of the electrical and magnetic components of EMF (50 Hz); the contents of carbon and nitric oxides, polychlorbiphenils, vapours and aerosols of compressor oil, ozone and radon; and an examination of the personnel's somatic health status had previously been made at the working places.

The examined cohort of the workers («linemen» and «power operators«) of the high-voltage substation consisted of male and female personnel. The first group of the subjects was responsible for operating the electrical installations (group 1) and the second group (group 2 -as controls) took care of the electrical installations disconnected from the power supply for a long time. The operation algorithm of the personnel of both groups was approximately the same.

Studies were conducted with the help of a package of anonymous questionnaires and special computer programs assisted psychological monitoring. The following social-and-psychological parameters were defined:

- Change of sociological status and psychological performance of personnel depending on the workday duration.
- Appearance of social and psychological deviation patterns depending on preceding work.
- Subjective evaluation of occupational factors effects on the professional activity.
- Significance of the effects of production, social and other factors on work capacity, the emotional and psychic status of personnel.
- Level of personnel alertness on Spilberger scale [6]; the psychological test evaluates occupational reliability of a person for the forthcoming complex responsible and dangerous work.
- Self-estimation of night sleep [7].
- Self- estimation of emotional state on the basis of SAM-test (self-feeling, activity, mood) [8].

- Level of neurotization and psychopathyzation of personality (LNP) [9]: testing allows one to select the persons predisposed to psychoneurotic pathology; the method is used in mental hygiene.

- Evaluation of professionally important qualities by the application of such methods as «reaction to the moving object» (RMO), «sensomotor reactions« (SMR), «operation with changing (in accordance with a special program) alphanumerical combinations» (ANC), the skill of «adding the numbers with switching» under conditions of the changing time intervals. RMO is sensitive with respect to different unfavourable factors of the working environment, which change both quantitative and qualitative response features [10]. The method allows one to model the conditions typical for certain components of the complex operator activity. ANC is used for studying the peculiarities of attention, ability to work at a forced rate and time deficit, some aspects emotional stability [11]. The method «adding the numbers with switching» is intended for studying the thinking, attention, operative memory, mental capacity to work and velocity of operation algorithm realignment.

In order to determine the correlation between the results of psychodiagnostic testing and the level of professional qualities, each operator taking part in the experiment was evaluated by the experts (managers of the substation) according to the specially developed methods, such as:

- occupational reliability under extreme conditions;

- honesty;

- skill to build relations within his/her team;

- working capacity.

The conducted studies have shown that the evaluation of social-psychological deviations of power facilities workers is rather complicated. The results of the social-psychological studies have revealed different levels of influence on the quality of professional performance and occupational reliability on the part of: working environment, sex, age, professional length of service, somatic health and emotional stress levels. Thus, the main influence upon health and self-feeling are noise (at the frequencies of 2 and 8 kHz, excess of the standard value reached 12 dB), electrical and magnetic fields, low temperature in winter and atmospheric pollution with different harmful admixtures (ozone, polychlorbiphenil

etc.). The subjective value of the health-affecting working environment factors of male group 1 was as follows: noise - 91%, EMF - 82%, low temperatures in winter - 43% and vibration - 17%. For male group 2 of these factors were accordingly 55, 50, 33 and 17%. More often the subjects of group 1 mention the following as the most harmful factors for health: EMF and noise (audiometry has shown a reduction of the auditory threshold at the frequencies of 4-8 kHz). The evaluation of the influence of labour and rest conditions on the capacity to work and self-feeling has shown that such parameters, as social-domestic conditions, the work environment, labour conditions, safety in production, diet and rest are noted more often by the males of the first group, than by those of the second (figure 1). The females of the first group define the organisation of labour, as the main factor of influence upon work ability and self-feeling (figure 1).

The results of the psychological examination of the males in the first group have not shown reliable differences against the second group in terms of such parameters as personal alertness, as well as personal evaluation of the emotional state (figure 2). However, in the first group of male operators a degree of neural patterns was somewhat higher, than in the second group. The test subjects explained this by their social-domestic conditions. For this professional group forecasts were made of a greater probability of development of alcoholism. A correlation of this factor with the age and length of service was observed (figure 3). The forecast was estimated by the special method for the »degree of alcoholic dependency« [12]. The sexual status of the male workers, as a rule, negatively correlates with their age. Such regularity was also observed in the personnel of group 2 (this age parameter also correlated with the length of service). However, in group 1 such a correlation was absent (figure 3). That is of certain interest and requires an additional study. The examination was conducted according to the recommendations on sexual pathology [13].

Amongst the male operators of group 1 and 2 no essential differences in such professionally important parameters as psychic stability, honesty or occupational reliability have been found. However, in the first male group the intellectual indicators and speed of thinking were somewhat higher, than in the second one. In the female subjects of group 1 as compared to group 2 all psycho-diagnostic signs (speed of thinking, intellectual ability, psychic stability, honesty and occupational reliability) were better (figure 4). The differences are conditioned by the fact, that in the females of group 2 these indices were sufficiently low.

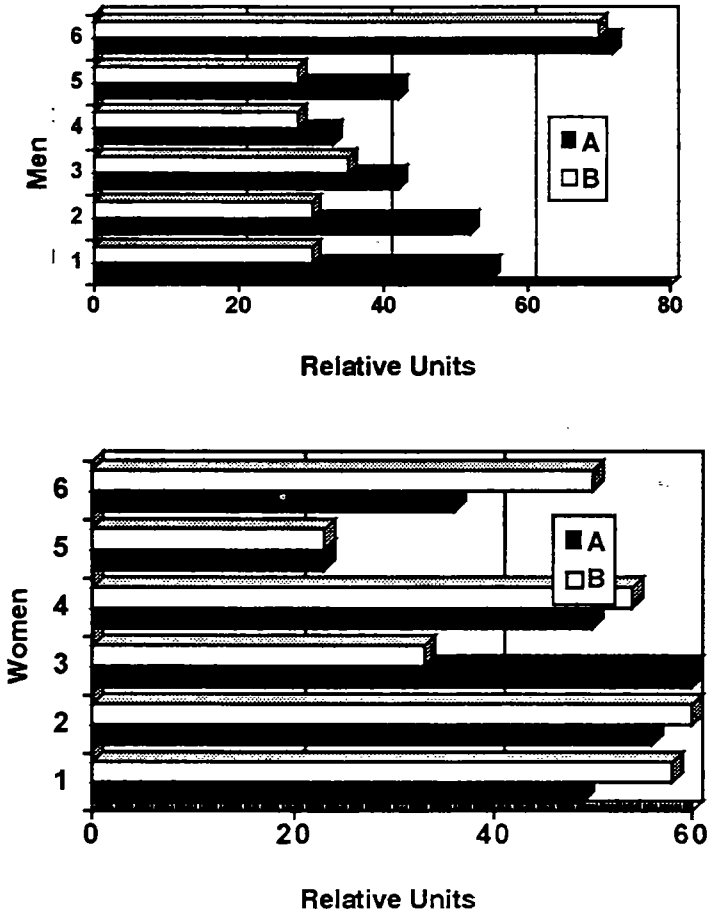

Figure.1. Subjective evaluation by the personnel of the role a physical, chemical and other factors of labour and social-domestic life on the working capacity and self-feeling.

A - group 1, B - group 2.

1 - physical and chemical factors;
2 - objects of labour and special clothing
3 - organisation of labour;
4 - psychological parameters
5 - conditions of diet and rest;
6 - social-domestic conditions.

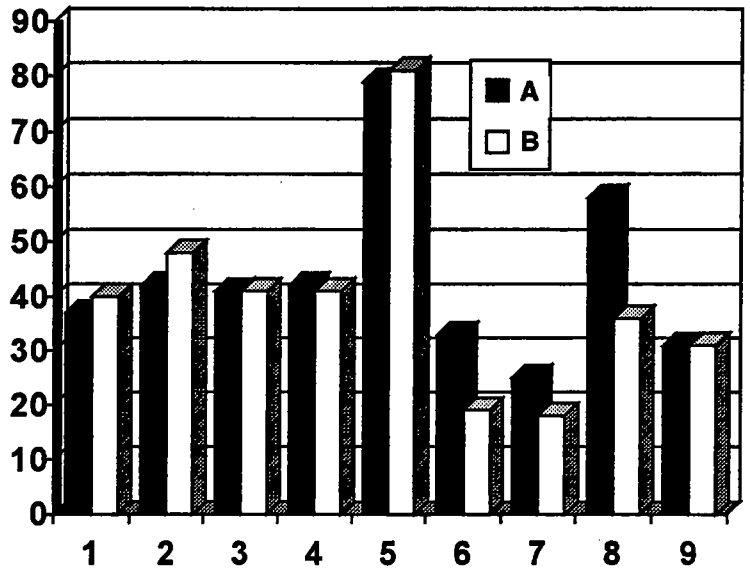

Figure. 2. Clinical-psychological examination of personnel of high-voltage substations "Belyi Rast". On axis of ordinates are shown values per *annum* or in *relative units.*

A - group 1, B- group 2.

1 - calendar age, *years.*
2 - functional age index, *years.*
3 - situational anxiety, *relative units*
4 - personal anxiety, *relative units*
5 - self-evaluation of emotional state (SAM test), *relative units*
6 - number (*percentage*) of personnel with an increased neurotic level
7 - average value of the "screening-test" on alcoholism (risk area of 20 *relative units*)
8 - number (*percentage*) of the high-voltage substation personnel within the risk area according to the "screening-test" on alcoholism
9 - summary indicator of sexual status, *relative units.*

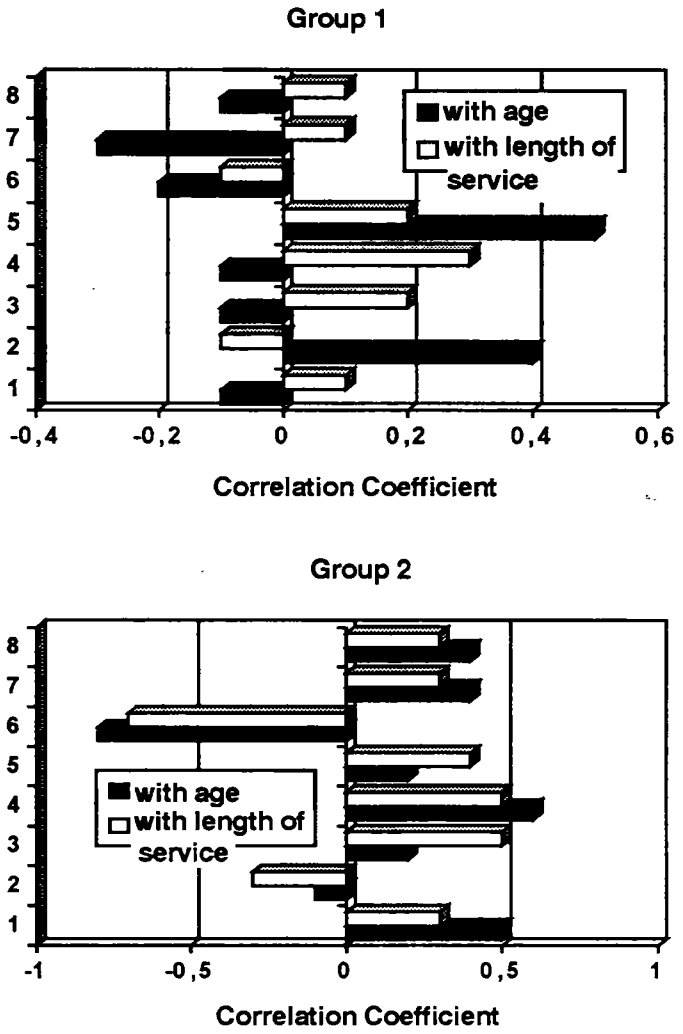

Figure 3. Correlation of clinical-psychological parameters with age and length of service for males of groups 1 (A) and 2 (B).

1 - situational anxiety; 2 - personal anxiety;
3 - self-estimation of night sleep; 4 - self-estimation of emotional state;
5 – alcoholisation level; 6 - sexual status;
7 - neurotic disorders level; 8 - psychopathological level

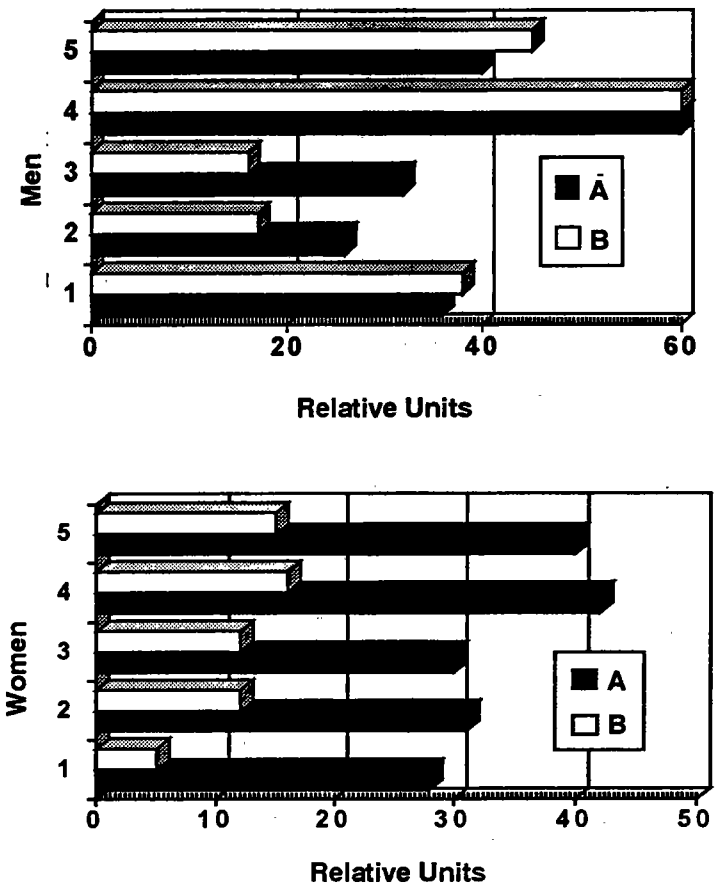

Figure 4. Psychological diagnosis of high-voltage substation male and female personnel

A - group 1, B - group 2

1 - integral index
2 - speed of thinking
3 - intellect
4 - psychic stability
5 - honesty and occupational reliability

The expert-analytical method of multivariate scaling was used for estimating the psycho-physiological status of operators according to such criteria as the integral index of cognitive processes, neuro-physiological patterns and psycho-emotional sphere. The level of such psycho-physiological quality indicators as the functional condition of nervous processes, distribution and switching of attention, individuality of thinking of the subjects in both groups were sufficiently high and had practically no essential differences. At the same time, in group 1 of the substation workers there was a tendency to a deterioration of some parameters: an increase in the amount of errors and in the integral index of differentiated sensomotor reactions, a rise of mistaken numbers revealed by the method of «adding with switching» (the method gives evidence of the psychic ability level and velocity of realignment of skills of activity to the problem-solving situations and when solving complicated knowledge-based tasks). A small decrease of these parameters in the first group of high-voltage substation workers can be explained, in some degree, by the reduction of the psychic abilities when dealing with spatial images.

The conducted studies of professionally important social and psycho-physiological parameters have revealed certain differences between the groups actively contacting with EMF (group 1) and not contacting with EMF (group 2). However, the deviations of most parameters should be interpreted as adaptive in response to the influence of ecological, psychogenic, social-domestic and other factors. Similar social-psychological monitoring certainly needs an additional array of data and a deeper comprehension of the results received.

In prospective there is a real need to set up a special databank on the social-psychological and biomedical status of the personnel of power installations with account taken of the data on production and environment monitoring. This databank must contain temporal, qualitative and quantitative features of the social, psychic and somatic health status of electrical workers; as well as a sufficiently broad informational and territorial scope within Russia, and, if necessary, within the framework of C.I.S.

The experience gained in compiling the computer database on the health status of the accident recovery workers of Chernobyl Nuclear Power Plant and the population, living in the areas polluted by radionuclides [14], can be useful for electric power enterprises of the Russian Joint-Stock Company of the Power Industry and Electrification (RAO «UPG of Russia»).

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THE NATURE OF ELECTROMAGNETIC HYPERSENSITIVITY: IDIOPATHIC ENVIRONMENTAL INTOLERANCE OR SPECIFIC PERSPECTIVE FACULTY: AN INTERDISCIPLINARY APPROACH TO ELECTROMAGNETIC HYPERSENSITIVITY

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Objectives

The effects of weak electromagnetic fields on the human organism are widely known. Investigations in recent experiments couldn't reveal any effects. Prospective investigations over long time intervals cannot be done by ethical reasons. That is why several retrospective studies have been carried out during which human suffering from unclear health problems were examined in their residential situation. An assessment of their historical field exposure of the last several years was accomplished. Even in these studies significant differences between patients and healthy control persons or between more and less field exposed persons couldn't be detected. However, the possibility could not be ruled out that certain persons react on field exposure situations more intensively than others. That is why we wondered whether a special oversensitivity to electromagnetic fields might be detected by a sophisticated method.

During the eighties, electromagnetic hypersensitivity has continuously gained significance and caused public concern as regards threshold values of fields intensities and the biological effects of electromagnetic fields. Generally speaking hypersensitivity to electricity is defined as the capacity to actually perceive electric and magnetic fields which cause bodily complaints and illnesses. In most cases those states of illness comprise anything from neurological disturbances to severe health problems. Our approach to the subject is based on the following hypothetical assumptions:

1. Hypersensitivity to electricity is an attempt to explain certain symptoms which have caused considerable pain in the person concerned, while all medical treatments hitherto employed, have failed.

2. The complaints of the patients are very similar to the symptoms which are described in the literature and the media as being typical for hypersensitivity to electricity. They might thus serve as an explanatory means.

3. Hypersensitivity to electricity is an allergic reaction to electric and magnetic stimulation. Environmental factors may have a chemical impact on the person involved and thus may reinforce the potential for the perception of electric and magnetic fields.

Methods

Studies asking probands directly if they can feel an electromagnetic field normally didn't provide satisfying results. Therefore we tried to elucidate unconscious influences in a statistical manner by exposing persons who are convinced to suffer from electromagnetic hypersensitivity to a series of field situations.

24 patients who are convinced that they do in fact strongly react to electricity as well as a similar number of the control group were confronted with the following experiment: After relevant information on personal living conditions, housing conditions and an anamnesis was obtained in each individual case, the patients were exposed to a magnetic field of 10 μT at a frequency of 50 Hz, generated by a coil. The magnetic field was activated for 2 minutes or disactivated, i.e. the succession of the intervals was determined on a stochastic basis and generated by a computer program. Hereafter the patients were informed that the electromagnetic field was shut off for another 3 minutes. After that they were confronted once more with the possibility that the electromagnetic field might be activated. The probability of the electromagnetic field being activated was 50% by means of calculatory computer programming. These phases were continued until a total time of 65 minutes was reached. While being confronted with the possibility that the electromagnetic field is switched on the proband was invited to talk about his perceptions or fill in a form serving as a scale, which had been prepared for that purpose. He was asked to give his opinion on whether the electromagnetic field had been switched on or not. On the basis of the information obtained, the score could be deduced for each single person. This test procedure was carried out twice. Since the results of the experiment do not provide enough validity as such, the investigation was complemented by a short internal and neurological examination, an anamnesis, a questionnaire concerning the symptoms felt as well as another one concerned with the individuals opinions on health and illness to preclude hypochondriac tendencies. Additionally, the patients were invited to talk freely about his personal living conditions.

The preliminary results

More women than men participated in the experiment altogether 17 women and 7 men. The results scored in the double-blind trial were as follows: In the two tests 15 patients scored more than 50% in either one of the two tests, but these results cannot claim major significance. Also the result of a control group cannot claim significance.

The symptoms most frequently named, referred to

- exhaustion (22 cases, 92%)
- sleep disorders (18 cases, 75%)
- concentration failure (16 cases, 67%)
- allergies (15 cases, 63%)
- back pains (14 cases, 58%)
- headache (13 cases, 25%)
- feeling of inner pressure (13 cases, 54%)
- crawling sensations (10 cases, 42%)
- depression (10 cases, 42%)
- cardiac pains (6 cases, 25%)
- hypertension (4 cases, 17%)
- IDI (Idiopathic environmental intolerance) (6 cases, 25%)

Most of the persons were aged between 42 and 55. On account of their symptoms 8 patients can only have part-time jobs or are not able to attend to work regularly (33%). 4 patients are not able of carrying out any work at all. They are now pensioners. 4 patients suffer from mobbing or from too high demands on the job. 5 patients suffer from a burn-out syndrom as a result of a long medical history. It is remarkable that 15 patients suffer from allergies, dental metals or prothesis dental, certain food ingredients, pollinosis, nickel, plastics, palladium, aspergillosis. With 7 probands increased levels of mercury, PCB, PCP, lindan, cadmium or formaldehyde could be stated. 10 patients had a removal of amalgame done, which relieved their symptoms. 10 others stated that they suffered from depression and only one patient of this group had received psychological assistance. Only 4 patients asked for psychological assistance and 12 sought help with a building expert assistance but no one has had a longer psychological treatment. 6 are classified as IEI. They are convinced that being intoxicated by chemicals, they are inclined to electromagnetic hypersensitivity. The internal and neurological examination didn't give signification results either.

Electromagnetic hypersensitivity should then be regarded as an environmental illness. Currently throughout Germany there exists an increasing awareness of health problems being caused by environmental factors.

Since illness which are due to the environment, have only recently received more attention in medical science, there is only limited knowledge in this field. This lack of knowledge and the consequent insecurity may lead to projections as to environment and its role in promoting illness. Projections are fostered both by the patients concerned and a society which is used to receiving clear diagnosis and therapies.

The patients feel that they are left alone with the symptoms they suffer from, since medical science does not provide the exact treatment that they would expect from a professional doctor. If an organic diagnosis cannot be made, patients will usually not receive medical treatment at all.

It is remarkable that nearly all patients accept this conception of illness. Hence they tend to emphasize a duality of body and a psyche. Psychological determinants and socially relevant hardships are generally not accept as causal determinants. They believe that one external factor is the cause of their complaints and are disappointed that there is no organic diagnosis. They think that psychological knowledge is prematurely applied to their case, and that, thus, their real suffering is not taken seriously. Many patients have developed a strong psychological tendency. They tend to attribute their symptoms to certain situations. This, in turn, will lead to the fact that the symptoms are stabilized. In the case of our patients, their perceptions and sensations extremely focused on electromagnetic fields. These cognitive causal links (an external factor is regarded as the cause of the illness) belong to the field of psychosomatic.

Electric current is everywhere and consequently the own body is selected as a location of symptoms, which will help to psychically stabilize the individual, when no adequate protection and no prescriptions against the manifold pressures and demands of society can be found.

The person who defines himself as hypersensitive has nearly the same symptoms as patients with hypochondric tendencies. A validated questionnaire showed, however, that there are no significant results which would prove, that these patients tend to hypochondria.

The hypothesis that a proneness to hypersensitivity to electricity is due to allergies or toxic substances in the environment has to be substantiated as yet.

We are indebted to Mrs. D. Klunker and Mrs. F. Gholamrezaei for technical assistance.

Summary

Results were evaluated and didn't reveal significant differences between hit frequencies of group of patients and group of healthy control persons. Correlations between hit frequencies and most frequently mentioned symptoms like exhaustion, concentration failure, headache, allergies, feeling of inner pressure and so on could not be found either. The symptoms most frequently named, referred to exhaustion (22 cases), sleep disorders (18 cases), concentration failure (16 cases), allergies (15 cases), headache (13 cases), feeling of inner pressure (13 cases), crawling (10 cases), depression (10 cases), cardiac pains (6 cases), hypertension (4 cases) and IEI (Idiopathic Environmental Intolerance, 6 cases). On account of their symptoms 8 patients can only have part-time jobs or are not able to attend to work regularly (33%). 4 patients are not capable of carrying out any work at all. They are pensioners. 4 patients suffer from mobbing or from too high demands on the job. It is remarkable that 15 patients suffer from allergies, dental metals or dental protheses, certain food ingredients, pollinosis, nickel, plastics, palladium, aspergillosis. With 7 patients increased levels of mercury, palladium, PCB, PCP, lindan, cadmium or formaldehyde could be stated. 10 patients had a removal of amalgame done, which relieved their symptoms. 10 others stated that they suffered from depression, and only one patient of this group had received psychological assistance. 6 are classified as IEI. They are convinced that being intoxicated by chemicals, they are inclined to hypersensitivity to electricity. In the two tests that were carried out, 18 patients scored more than 50% in either one of them, but these results cannot claim major significance, compared with the control group.

Conclusion

Regarding the small number of persons integrated into the study the conclusion of the evidence of an electromagnetic hypersensitivity independent from symptoms is not yet possible. Even if a slight tendency towards the above mentioned negative correlation may be observed. Patients who are convinced that they are hypersensitive to electricity do not have a history of psychiatric illness and do not meet criteria for diagnosis used in psychiatry. It is remarkable that all patients attempt to find a cause which would explain their symptoms and have tested several traditional methods which regard to their efficiency. Most of them are disappointed and refuse to accept definitions of illness used by formal medicine. They tend to emphasize a duality of body and psyche and wish that one single cause be at the root of their problems. Psychological determinants are

socially relevant hardships are generally not accepted. It is thought that a premature recurrence to psychiatric knowledge for the explanation of psycho-social conflicts is too often the case, and that, consequently, the real suffering is not taken seriously. The hypothesis that a proneness to hypersensitivity to electricity is due to allergies or toxic substances in the environmental has to be substantiated as yet.

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EFFECT OF VIDEO DISPLAY TERMINAL IRRADIATION ON TUMOUR DEVELOPMENT IN MICE

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Recent experimental and clinical observations suggest that electromagnetic fields (EMF) of different frequencies and strength could stimulate tumour development (6,8,9,10, 13,15). One of EMF sources is the irradiation induced by widespread personal computers, or more exactly, by video display terminals (VDT) (1). It was reported that VDT users have an increased risk of brain tumours, and women have an increased risk of miscarriage, and progeny have an increased risk of malformations (13). No convincing confirmation of this observation, however, is yet available.

This work presents the results of an experimental study on the effects of exposure to the irradiation of VDT of personal computers on the tumour development in mice as well as on some mechanisms of its action. The specific aims of the study included the effect of VDT on 1) spontaneous carcinogenesis, 2) urethane-induced carcinogenesis, 3) tumorigenesis induced by estradiol-dipropionate (EDP) and 4) the growth of various transplantable tumours. The endocrine status of the animals (mice and rats) exposed to VDT has also been evaluated. Additionally the modifying influence of screen filter "Ergostar" on the effects of VDT-irradiation on tumour development has been studied as well.

Nine hundred of female mice of different strains were purchased from «Rappolovo» Animal Farm of The Russian Academy of Medical Sciences and 54 male LIO rats were received from Animal Department of N.N.Petrov Research Institute of Oncology. PC/AT-286 computer (Litron Professional Co, Singapore) and EGA colour monitor (model No.CA-1401, 230 V; 50 Hz; 0.4 A; Taiwan) were used for irradiation. One of the group of animals was exposed to the same type of VDT supplied with a screen filter (SF) "Ergostar G-14" (Ergoline, Austria). For exposure the cages with mice, covered with a perforated Plexiglas cover, were placed under PC VDT screens. The distance between the VDT screen and the bottom of the exposed cage was 38 cm. The exposure regimens varied from a single exposure (1 hour or 3 hours) to 1-hour or 3-hour irradiation 5 times per week for 1 to 3 weeks or for their entire life.

The measurements of the parameters of EMF were performed at the level of the cage bottom with exposed and non-exposed mice and also outside the irradiation zone. EMF dosimetry has shown that SFs significantly decreased the

illumination of the exposure field. (from 22-27 to 5-12 lux) as well as the intensity of the static electric field (from 3-9 to 1-2 kV/m). The parameters of ELF of AC magnetic field induction were 0.5-0.6 μT and SF failed to influence that. The details of dosimetry have been given elsewhere (4).

Five series of the experiments have been performed in all. Student "t", Wylkokson-Mann-Whytney "U", exact Fischer tests as well as Peto's test recommended by IARC for the evaluation of carcinogenicity were used for a statistical treatment of the results.

In the 1st series of the experiment female outbred SHR mice were randomly subdivided into 3 groups. Group 1 served as controls, groups 2 and 3 were exposed to VDT and VDT+SF irradiation, respectively, 1 hour per day 5 days a week during the whole life. Additionally males and females irradiated with VDT 1 h/day x 2 weeks were mated and their progeny were kept under observation for natural death outcomes. The progeny of intact mice served as controls. Long-term exposure to VDT regardless of SF was followed by a small decrease in the body weight. There were not any statistically significant changes in the survival of mice in these experiments.

Mammary and lung tumours as well as leukaemias were predominant in all groups. The tumour incidence in groups 1, 2 and 3 was 45, 31 and 46 %, respectively. Exposure to VDT alone failed to change the dynamics of total tumour development in comparison to the controls, while in the mice exposed to VDT + SF there was some increase in the tumour appearance in the middle of the observation period (12).

The total incidence of tumours in the progeny of VDT-irradiated mice was significantly increased in comparison to the controls in males (54% vs 8%) as well as in females (59% vs 23%). The increase in the mammary carcinomas incidence in females (56% in VDT group vs 15% in the controls) and in lung tumours in males (45% in VDT group vs 4% in the controls) has been observed (14).

In the 2nd series of the experiments 3-month-old female SHR mice were subdivided into 3 groups and exposed to VDT or to VDT + SF as in the series 1. At 1st, 8th, 54th and 61st days of the experiment all the mice were exposed intraperitoneally to injections of lung carcinogen urethane in a single dose of 20 mg/mouse. All the mice were under observation up to one year after the 1st injection of the carcinogen and then were sacrificed. The majority of tumours developed were lung neoplasias. Some mammary carcinomas, uterine polyps and leukaemias also developed. The exposure to VDT alone was followed by a slight

increase in total or malignant lung tumour incidence and in uterine polyps as compared to the controls. At the same time in the mice exposed to VDT + SF a significant decrease in the incidence of total tumours and in the multiplicity of lung tumours, in comparison to those in the mice exposed to VDT alone, was found. A decrease was observed in the number of small (< 1mm in diameter) lung tumours in the mice exposed to VDT +SF (2,4).

In the 3rd series of the experiments 3-month-old female SHR mice were subdivided into 6 groups. The mice were subcutaneously treated with estradiol-dipropionate (EDP) in a single dose of 10 μg/mouse in olive oil or with solvent and were exposed to VDT or VDT + SF as in the previous series of the experiment. The animals were under observation until their natural death.

The majority of the neoplasms developed were mammary, ovarian and uterine tumours. In the mice exposed to VDT + EDP a slight increase in tumour incidence and a decrease in tumour latency have been found. SF alleviated these effects. The total tumour incidence as well as the incidence of mammary and ovarian tumours in the mice exposed to the oestrogen only were 14, 11 and 0%, respectively. These figures were 26, 19 and 7 % in the mice exposed to VDT + EDP and 3, 3 and 0% in the group exposed to VDT + SF + EDP (12).

It was suggested that long-term exposure to VDT irradiation suppressed the immunity of the animals because the irradiated animals in the 1st, 2nd and 3rs series of the experiments more frequently revealed intercurrent diseases in comparison to the control mice.

In the 4th series of the experiments SHR, Balb/c and DBA/2 were used for the study of the effect of VDT irradiation on the growth of transplantable tumours. Nine experiments were conducted. Ascite Ehrlich carcinoma was inoculated subcutaneously (s.c.) into SHR mice and intraperitoneally (i.p.) into Balb/c mice. Leukaemia L1210 was inoculated i.p. to mice DBA/2. In all these experiments the animals with transplanted tumours were subdivided into three groups: control, VDT and VDT + SF. The exposure (1 hour or 3 hours/day) was started two weeks before or on the next day after tumour grafting and was performed during the life span of the tumour-bearing mice. VDT irradiation started after transplantation of tumours in the majority of the experiments, stimulated the tumour growth, while an application of SF alleviated this unfavourable effect of the irradiation. Thus, in the experiment with Ehlrich carcinoma the mean tumour size in VDT-irradiated mice was 88 % bigger than that in the controls on the 12th day after grafting, whereas in the mice exposed to VDT + SF - only 18 % above the control value. On the contrary, exposition to VDT before grafting resulted in the inhibition of tumour

growth. For example, in the experiments with SHR mice a statistically significant inhibition (by 43%) was observed on the 14th day after tumour transplantation (11). One of the explanations of the contradictory results is the variety of the EMF effect of VDT irradiation on the immunity level: high frequency EMF stimulates antibody formations and macrophages activity whereas low-frequency EMF stimulates the proliferative activity of lymphocytes.

In the 5th series of the experiments the effect of VDT irradiation on the endocrine status of the animals was studied. Night serum prolactin (RIA) and melatonin (ELISA) level was analysed in 3-month-old male rats after a single exposure to VDT irradiation (1 hour or 3 hours) and in rats exposed to VDT 1 hour 5 times a week during 3 weeks. It was shown that the exposure to VDT resulted in a 2-fold decrease in serum melatonin level in comparison to the controls regardless of the dose of the exposure. The serum proactin level was slightly increased in the irradiated animals (3). There is evidence of the promoting role of these hormonal shifts in pathogenesis of mammary tumorigenesis (8,15).

The effect of VDT irradiation on the maturation was evaluated using the test on vaginal opening, and the test on the oestrus function using monitoring of vaginal smears. The vaginal opening in the control mice was estimated in the mean on the 62nd day of life whereas it was the 50th and 56th days in the mice exposed to VDT or to VDT + SF during 1 hour/day 5 times a week starting at the age of 1 month. This finding suggests the acceleration of puberty onset in VDT-exposed animals (3). It is well known that precocious menarche is a risk factor for breast cancer (7). Long-term exposure to VDT started at the age of 3 months was followed by a significant increase in the number of mice with persistent oestrus syndrome. Thus, at the age of 12 months only 6% of the control females revealed the persistent esters syndrome whereas it was 48% and 44% - in the mice exposed to VDT or to VDT + SF. At the age of 18 months these figures were 57, 92 and 91%, respectively (3). The anovulatory syndrome in rodents as well as in women is a risk factor for reproductive system malignancies (7,15).

Thus, the results of our experiments suggest that VDT irradiation should be considered as «a factor of low intensity» influencing the endocrine and immune status of the organism. Long-term exposure to VDT irradiation leads to slight stimulation of tumour development in female mice and in the progeny of females and males exposed before mating. VDT irradiation is a complex of different EMF the biological effects of which are not yet clear. «Melatonin hypothesis» is one of possible explanation of EMF effects (15). According to this hypothesis EMF decreases melatonin production by the pineal gland. This hormone has anti-tumour and anti-carcinogenic potential and inhibits free radical processes. It was shown

that EMFs, including VDT irradiation, influence free radical processes (3,5) which could be a cancer risk factor. Taking into the consideration the available data on the co-carcinogenic action of various EMF (8,10,15) it is difficult to deny a possible hazard of VDT irradiation. Maximum restriction of the exposure time to VDT irradiation could be recommended.

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BIOLOGICAL and THERAPEUTIC EFFECTS OF MAGNETIC FIELDS IN ANGIOLOGY

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Effects of a stable magnetic field (SMF) on the microcirculatory bed

As is well known, the idea that SMFs affect medico-biological processes has its roots in hoary antiquity. However, its history has seen periods of general enthusiasm alternate with ones of outright rejection of its scientific or practical value. It should be said that in our days one also comes across manifestations of scepticism, negative attitude and opposition concerning this problem. The reason for this is quite clear: in spite of a wealth of the empirical materials accumulated by many generations of researchers they still lack a convincing theoretical foundation.

Thus, in full conformity with the relentless rules of functioning of the contemporary science machine, no facts will be recognised by the scientific community unless and until the above condition has been fulfilled. This, however, does not mean that magnetic fields have lost their biological activity.

Since 1954 specialists of the Clinic of hospital surgery have been, and still are, extensively and successfully using SMFs for treatment of patients with vascular pathology (A.M. Aminev et al., 1954-1982; B.N. Zhukov et al., 1975-1994, etc.).

The present paper is based upon the results of an examination of 256 in-patients suffering from chronic venous insufficiency (CVI) of lower limbs. Selected for the investigation were only those CVI patients who had oedematic or varicose forms of post-thrombophlebitis (PTP), were aged between 20 and 45, had no concomitant pathology and had satisfactory functional indices. Investigations of SMF effects on the speed of excitation conduction through a nerve fibre and on the membrane depolarisation potential of axons were conducted on healthy sport lovers (volunteers from the Institute clinics, aged 18 to 25, and also on the co-authors). Table 2 shows the distribution of the patients in terms of age, sex and character of pathology. Also studied were the factors of PTP etiology (see Table 1).

A great number Russian and non-Russian investigations have been devoted to the significance of CVI etiology factors. Among those are: heredity (Sh.A. Gulordava, V.F .Razin, 1974; A.K. Revsky, T.Zh. Zhurayev, 1980; Gundersen,

Hayge, 1969), hormonal balance disorders (R.S. Kolesnikova, 1977; V.I. Kulakov et al., 1982; Barwin, 1976; Cockett, 1976), traumas, acute thrombophlebitis of superficial veins (V.S. Savelyev et al., 1972; A.K. Revsky, 1975; Rich Hodson, 1975; Ruckley, 1977), increased abdominal pressure, as well as occupational, weather and ecological factors (A.G. Kovaleva, 1967; L.I. Klioner, A.V. Pokrovsky, 1978; Borschberg, 1967 et al.).

Table 1
Etiological factors of post-thrombophlebitis (PTP).

Etiological factors	Females	Males	Total
Hereditary predisposition	21 (12.3%)	18 (21.2%)	39 (15.2%)
Pregnancy and childbirth (endocrine shifts)	48 (28.01%)	-	48 (18.7%)
Lower limb trauma	14 (8.18%)	20 (23.5%)	34 (13.3%)
Occupational hazards	3 (1.75%)	5 (5.9%)	8 (3.1%)
Surgical intervention	28 (16.3%)	7 (8.2%)	35 (13.6%)
Infectious diseases	6 (3.5%)	1 (1.2%)	7 (2.7%)
Varicosis	44 (25.7%)	32 (37.6%)	76 (29.7%)
Cause unknown	7 (4.1%)	2 (2.3%)	9 (3.5%)
Total number of subjects examined	171 (100%)	85 (100%)	256 (100%)

Table 2
Forms of chronic venous insufficiency (CVI), sex and age of patients.

Forms of PTP	aged 20-30 female/male	aged 31-40 female/male	aged 41-45 female/male	m/f index
1 Oedematic	24/7	32/18	41/16	2.4
2 Varicose	14/9	28/15	32/20	1.7
3 Total	38/16	60/33	73/36	256
	2.3	1.3	2.02	2.0

Note: shown in brackets is the m/f index in the respective age group.

The great variety of the causes is in itself an indicator of the polyethiological character of the disease, while also pointing to our lack of sufficient knowledge in that matter.

As follows from our analysis, it is only in 13.3% of the cases (traumas) that we can pinpoint the direct path of pathological action on veins of lower limbs. As to all other cases (infections, surgical intervention, occupational hazards, hereditary predisposition), the patho-physiological chain resulting in varicosis or thrombosis

of deep veins remains still unclear. We assume that this group of factors should be regarded as a non-specific stress with its (now already studied in great detail) sequence of central, vegetative and endocrine mechanisms resulting in a restructuring of peripheral tissues (F,Z. Meyerson, 1981). Reaction to the stress depends on the initial hormonal background of the body as well as on the degree of mobilisation of its defensive mechanisms. A constitutionally insufficient or, on the contrary, excessive mobilisation which is inadequate in relation to the degree of primary effect is manifested in the form of the so-called "adaptation disease" (G. Selye, 1961, 1975). Recent studies established the existence of certain alternative paths of action of the constitutional norm on stress (V.V. Rozen, 1980). One of them follows the "classical" mechanism, described by Kennon as far back as 1926, with the activation of pressor reactions, increased blood coagulability, hyperglycemia. This path is realised through the sympathetic-adrenal neuro-endocrine system. Another path is mostly connected with depressor reactions of the parasympathetic nervous system, while its hormonal component is represented by somatotrophin. On the basis of our analysis and in the light of the known stress syndrome mechainism we believe that CVI can be regarded as an adaptation disease, while varicosis can be regarded as insufficient adaptation of the venous bed according to the second type. Deep vein thrombosis should be regarded as an excessive response to stress with an inadequate pressor reaction of veins, spasm and hypercoagulation, i.e. as a response according to the first "classical" Kennon-Selye type.

We considered it necessary to initiate a discussion of this problem in order to stimulate further investigations of the matter, all the more so since, as far as we know, the concept of stress syndrome and adaptation diseases, as applied to vein diseases, has not been dealt with in medical literature. On the other hand, the status of the regional blood circulation in PTP patients in terms of its directivity, qualitative characteristics, pathogenetic mechanisms and stereotypical convergence of the principal types of disorders, has much in common with the disorders of haemodynamics during operational stress and thus may serve as its model.

An "Eya" electromagnetic installation of a unique design (of the "Polyus" type) was used. It was made up of two mutually displaceable solenoids fixed by a special device on a horizontal stand. Magnetic induction levels can be gradually adjusted within the 1 - 200 mT range. The subject under study was placed axially in relation to magnetic field lines of force. While conducting the investigation we were guided by the rules stated in the methods directives "Occupational Hygiene and Prevention of Unfavourable Effects of Electromagnetic Waves on Workers" (1973) issued by the Russian Health Ministry.

Magnetic induction is related to the strength of the external magnetic field - H in accordance with the equation: $B = \mu + H$. The unit of magnetic induction in the C.G.S system is the gauss (G), and in the SI system the tesla (T). $1G = 10^{-4}T$.

Magnetic field strength with circulating current is determined according to the following formula: H=0.2 I/r where H- strength in oersteds, I- strength of current in amperes, r - the circle radius. Magnetic flux is calculated according to the formula: $\Phi=C$ (a - a), where Φ- magnetic flux. C- the instrument (flux meter - milliweber-meter) constant per instrument scale unit, a - initial instrument readings, a - maximum deviation of the instrument pointer, N - number of turns of the measuring coil. Magnetic induction can be measured according to the following formula:

$=\Phi / S;$

where - magnetic induction in mWb/cm,

Φ - magnetic flux in mWb,

S - area of the measuring coil in cm.

The choice of a magnetic field biodose is made on the basis of thermovisual control, with dose values usually in the 2.5-8 mT (25-80 oersted) range. The screen of the thermovision device displays the luminosity potentiation of a limb placed in a magnetic field.

Greater luminosity of tissues in a stable magnetic field points to improved conditions of their blood supply. Therefore, in order to reproduce IMI vascular effects it is quite unnecessary to try to generate high levels of magnetic field induction. That was why in our clinical practice (treating CVI patients) we used only low inductivities (2.0-10.0 mT). For special investigations the entire resolution capacity of the installation was made use of.

In PTP patients a certain connection is observed between the status of microcirculation, transcapillary exchange and the form of the disease. The greatest changes are recorded with the oedematic form of PTP. These changes are governed by Landis' rule (Landis 1930). As a consequence of the protein leaving the venous segment of the microvascular network the colloidal-osmotic blood pressure is reduced and the tissue colloidal pressure increases, i.e. their difference is reduced which, under the conditions of a relative stability of the hydrostatic pressure (or, more exactly, the difference between the hydrostatic blood pressure and the

hydrostatic tissue pressure) strengthens the fluid filtration from the vascular bed into the extravasal space. Higher permeability of the histohaematic structures leads to the sodium leaving the capillaries thus increasing the osmotic pressure of the extracellular fluid and taking the liquid part of the blood with it. This promotes the formation of an oedema in the lesion area which results in a change of the aggregate state of the extravasal space tissues i.e. in their hydration, deterioration of their properties as a diffusion medium for oxygen, and, accordingly, in deterioration of tissue trophicity. Hypoxia develops. Tissue biochemical functioning is rearranged towards the glycolytic mode. This, however, does not sustain the stability of the oxidation-reduction potential. The arterial-venous oxygen difference is reduced due to the activation of shunting mechanisms. With venous hypertension the pressure gradient (P) is reduced which, under the conditions of a relative stability of the tissue pressure (P_T), causes a reduction of the transmural blood pressure $P_{TM} = - P_T$.

If the critical occlusion value is reduced the tonic tension developed by the vascular wall of arterioles "tampons" the arteriole lumen "ejecting" the blood flow into the system of cross-over vessels.

The developing arterial-venous shunting at partial occlusion (PTP) is a defence-adaptation reaction as it reduces the hydrostatic pressure in the microcirculation areas and thus reduces damage effects of the internal medium factors on the tissue. This is a decompressor reaction.

However, along with this defence-adaptation reaction, another reaction develops which basically has a manifestly unfavourable effect on the metabolising tissue. What it means is this: as a result of the arterial-venous shunting there occurs a sharp reduction of the arterial perfusion of the tissues, the tissue p02 falls to a critical level, under-oxidised products accumulate in the extravasal space of the microvascular basin. In the conditions of inhibition of the vasomotion mechanism, i.e. correlation between the effects of neurogenic and humoral regulation factors, toxic effects of metabolites on the tissue and vascular wall become apparent. Let us call it a reduction reaction. Thus the character of vascular and tissue reactions at venous hypertension (partial venous occlusion) in qualitative terms almost completely reproduces the picture of histovascular shifts at surgical stress, and the starting mechanisms are probably the same.

With the varicose form of PTP the histovascular shifts in the microvascular sector have the same qualitative base but are less pronounced. Evidently, varicose veins are still capable of performing a certain decompressive function and thus reduce the shunting effect which develops at distal venous hypertension.

Table 3
Status of transcapillary metabolism in PTP patients

Indicators	Control	PTP	
		varicose	oedematic
Capillary filtrate in ml	2.03±0.02	8.17±0.45	14.57 ±0.47
Loss of protein	1.0±0.12	1.88±0.29	4.06 ±0.47
Na content (mmol/l)			
Arm	147.03 ± 0.3	147.76 ± 0.27	146.48 ± 0.38
Leg	146.36 ± 0.2	144.36 ± 0.35	134.25 ± 0.82
П	20	25	25
P	-	<0.05	<0.05

Table 4
Indicators of tissue oxygenation system in PTP patients

Indicators	Control	PTP	
		Varicose	oedematic
pa02 mm of mercury	124.2 ± 3.8	1 18 ± 4.2	122.2 + 3.1
pv02 mm of mercury	48.3 ± 3.3	50.2 ±2.2	49.9 ± 2.8
ecp02 mm of mercury	42.6 ±0.4	28.5 ±0.4	12.4 + 0.8
D (%)	100	66.6±0.5	30.1 ±0.6
Sa02(%)	90.42 ± 4.2	91.73 + 2.2	90.88 ± 3.5
Sv02(%)	46.6 ± 0.5	62.4 + 1.3	70.7 ± 0.5
A-V g/100ml	9.24 ± 0.6	6.13± 0.5	4.28 ± 0.5
ec ОБП in mV	-42.0 + 0.3	-64.4 + 3.6	-78.8 ±.3.6
П	38	20	20
P	-	<0.05	<0.05

Treatment of CVI patient with a SMF was (initially) conducted in order to obviate sludge formation in the microvascular system, as in our earlier investigations (B.N. Zhukov, L.A. Trufanov, S.M. Musienko, 1977,1978,1979) we observed a de-aggregation and hypocoagulation effect of magnetic fields. The idea was, on the one hand, to improve the rheological properties of the blood and consequently the conditions of microvascular perfusion, and on the other hand, to prevent thrombus formation in CVI patients, i.e. to influence one of the starting mechanisms of this pathology. The hypocoagulation effect of SMF was reproducible to such an extent (even with an insignificant field induction) that it was considered necessary to take this factor into account while drawing up practical recommendations for application of magnetic fields in clinical practice. This property of SMFs must also be taken into consideration by those operating the installation.

Table 5
Isoenzyme spectrum of LDH and MDH in the skin of PTP patients.

Isoenzymes %	Control	PTP	
		varicose	oedematic
LDH1	0.65 ± 0.4	-	-
LDH2	9.66 + 0.59	8.20 ± 0.60 1	1.66 ± 0.85
LDH3	10.46 ± 0.8	7.98 ± 0.60	12.05 ± 0.91
LDH4	35.0 ±. 1.6	35.72 ± 0.7	36.05 + 1.13
LDH5	44.2 ± 1.32	48.55 +1.22	40.16 +2.28
MDH1	3.60 ± 0.20	-	-
MDH2	69.6 ± 1.40	53.52 ± 3.36	56.18 + 1.65
MDH3	26.7 ± 1.00	46.72 ± 3.44	43.50 ± 1.60
П	20	25	25
P	-	<0.05	<0.05

Table 6
SMF effects on the conditions of transcapillary exchange (TCE) in the norm and pathology

Indicators	Control	PTP	
		varicose	oedematic
Capillary filtration in ml	2.06 ± 0.02	8.46 + 0.38	9.98 ± 0.55
Loss of protein (%)	1.08 ± 0.08	1.86± 0.26	2.40 ± 0.42
Na content (mmol/l) arm	146.89±0.3	146.6±0.4]	146.55 + 0.2
leg	-	142.2 ± 0.4	139.55 ± 0.22
П	12	18	20

P < 0.05 in relation to the value of the indicators outside MFs.

Later it was discovered that the biological effects of SMFs are not limited to hypocoagulation properties. Below are the results of our observations.

From the analysis performed it follows that a low-induction SMF has no significant effect on the conditions of transcapillary exchange in healthy humans, while in PTP patients with the varicose form it produces an extremely insignificant (3.5%) increase of filtration processes (which is probably related to dilatation of the changed vascular wall). An expressed therapeutic effect was found in PTP patients with the oedematic form, where an intensification of extravasate reinfusion processes was registered (31.5%) along with stabilisation of proteins (52%) and electrolytes (3.7%).

With increased magnetic induction comes a reduction of extracellular OVG1. However, no linear dependence is noted. We registered the redox-metric signal reaching a "plateau". One can assume the activation of certain adaptation mechanisms that stabilise the tissue electrogenesis.

There is no official ban on the application of high-induction EMFs in medical practice. Nevertheless, we conducted our experiments on volunteers from among those concerned with the problem. The patients reacted to SMFs in the conventional induction range (2.5-10 mT) by developing systemic hypotension, brady- or tachycardia, and in some an orthostatic collapse could develop after an experimental session. Many patients, on the contrary, felt a surge of energy, an improvement of eye-sight and a sharper perception of smells during and after a session. Common for both sick and healthy subjects was the diuretic effect of magnetic fields which often hampered the course of the experiments and thus is well remembered by the authors.

Table 7
Indicators of tissue oxygenation system under the influence of SMFs

Indicators	Control	PTP	
		varicose	oedematic
pa02 mm of mercury	122.2 2.5	118.6 2.0	118.0 2.2
pv02 mm of mercury.	49.3 1.6	49.9 1.8	50.2 0.9
ecp02 mm of mercury	39.4 0.2	25.1 0.2	20.2 0.8
D (%)	92.5 0.9 (-7.5 %)	58.9 0.4 (-6.7 %)	47.4 0.4 (+17.3%)
Sa02 mm of mercury.	90.1 2.4	92.1 1.7	91.6 1.8
Sv02 mm of mercury.	52.2 0.5	59.5 0.8	62.2 0.5
A-V g/100ml	3.0 0.3 (-13.4%)	6.8 0.1 (+3.2%)	6.0 0.05 (+40.2 %)
ОВП mV	-58.1 0.05 (-27.7%)	-62.4 2.4 (+3.2%)	-63.7 1.2 (+19.2%)
n	19	28	35

P < 0.05 in relation to the value of the indicators outside MFs.

In general, within the 10-30 mT range the inhibition effect of a SMF on the electrogenetic activity of tissues is expressed to the greatest degree which made it unnecessary to try to generate high levels of magnetic field induction.

The influence of a SMF on the electrogenetic tissue activity produced some unexpected results in PTP patients (especially with the oedematic form). An analysis of the isoenzyme spectrum of LDH and MDH revealed a shift in the

activity spectrum towards anaerobiosis on the part of LDH, expressed by the activation of myochondrial MDH 3 against the background of a substantial reduction of cytoplasmatic MDH 2. The partial oxygen pressure in the extracellular medium was 78.5 mm of mercury, with an almost 80% reduction of the diffusion properties of the extravasal space tissues. The volume of «transit» blood flow through tissues is significant (reduction of the arterial-venous difference according to 02) and one observes a low initial level of the oxidation-reduction potential (-79.6mV). These changes were similar to those observed at surgical stress at the stage of destabilisation. Exposure to a SMF in this case resulted in an increase in the volume of the "nutritive" blood flow through tissue (A-V increase), increase of partial pressure 02 in the extracellular volume (oestrone 02 increase), intensification of extravasate reinfusion and, accordingly, improvement of the properties of the extravasal space tissues as a diffusion medium for oxygen, emergence of a tendency to recover the initial aggregate state of the key enzymes of the respiratory chain (LDH, MDH). Evidently, the entire array of these causes ensured a 16.9% increase of the extracellular redox potential, though, as is known, an MF load on a healthy human reduces the bioelectrogenase level. Below is a description of the most typical dynamics of the redox potential in the PTP (oedematic form) patients exposed to SMFs.

Table 8
Isoenzyme spectrum of LDH and MDH in the skin of limbs under the influence of SMFs

Indicator	varicose PTP		oedematic PTP	
LDH1	-		-	
LDH2	10.37	0.69	8.56	0.82
LDH3	11.37	1.48	7.06	0.39
LDH4	37.62	1.58	39.78	1.92
LDH5	40.62	1.58	44.28	2.00
MDH1	-		-	
MDH2	57.9	1.85	66.9	2.84
MDH3	42.05	1.85	33.0	2.79
П	22		16	

$P<0.05$ in relation to the value of the indicators outside MFs.

In the PTP11 (varicose form) patients we registered a significant dispersion of dynamics of the redox-metric index, extracellular p02 and diffusion coefficient 02 (d). One observes a shift in the activity spectrum of cytoplasmatic and mitochondrial dehydrogenases synchronised with the oxygen volume taken by tissues from the vein and, accordingly, with the fluctuations in the arterial-venous oxygen difference (A-V).

It seems that the principal source of "interference" in this case are the effects of blood deposition in the veins affected by varicosis in combination with a vasodilatory effect of SMFs on them. This has to be taken into consideration while determining the indications for MF treatment of patients with this form of PTP.

As a matter for discussion we must state: a connection between metabolism with the generation of electric potentials in living tissues is unquestionable, however, different researchers treat it differently. Nevertheless, on the common metabolic approach basis, a rapprochement or even coincidence of the postulates of the membrane and protoplasmatic concepts of biological electrogenesis is taking shape. The only question is whether the role of metabolism is limited to the renewal of the energy gradient of the protoplasmatic structures, or some exchange reactions are in themselves one of the executive links in the working mechanism of regeneration of the potentials.

A detailed analysis of these postulates was not intended by the authors of the present investigation, and the objectives of the latter were limited to detecting an interrelation between the level of metabolism, its internal structure and the state of the oxygen supply system.

These connections are most vividly manifested in the conditions of regional ischemia which can be a result of either a peripheral arterial occlusion (ligation of an artery in our experiment), or of distal venous hypertension. In the latter case our study of the parameters of tissue metabolism and of oscillations of the redox-metric signal of extracellular spaces was conducted on CVI patients. The matter is that, in the conditions of distal venous hypertension, the leading pathogenic link is microcirculation disturbances which are expressed through opening the arterial-venous shunts and increasing the volume of «transit» blood flow through tissue.

Thus here we also have a model of the conditions of regional ischemia which, in combination with the strength and dissociation of membrane processes, are capable of even gross displacements of the electrogenetic factors beyond the normal indicators of an unstable equilibrium. This technique of simultaneous study of energy processes in tissues at peripheral arterial occlusion in one case, as well as the study of kinetic parameters of oxygen exchange at functional shifts of the microvascular section in the other, makes it possible to gain an understanding of the MF application points in a biosystem.

From the essence of our investigations it follows that SMF effects on the electrogenesis of such a non-differentiated polymorphous tissue as PCT are mainly manifested through the initially dominating influence on the vasomotor

microcirculation activity. This results in alternating differences of partial oxygen pressure in the extravasal space to which the dehydrogenase activity spectrum of Meyerhof-Embden and Krebs cycles is adapted. Direct SMF influence on the electrogenetic tissue activity is manifested as inhibition of membrane processes (reduction of OBP in healthy subjects) and is masked by the presence of vascular reactions.

Thus the electroenergetic activity of tissues, which is realised through activation of the enzymatic systems of energy complexes of both cell membranes and cell protoplasm, is determined by the functional status of the microcirculatory system and transcapillary transfer as the systems ensuring blood supply to tissues on the one hand, and by the inhibiting effect of SMFs at the membrane level on the other.

If one considers the vasodilatory effect of MFs as well as the fact that myorelaxation is a passive process, it can be assumed that the basic SMF application point is the neuroreflex link regulating the functional status of the microvascular network and the function of transcapillary exchange and thus indirectly affecting the neutrotrophilic control of the structural-functional organisations, on the feedback principle, through enzymatic systems of the energy structures of cells. This action is combined with a direct inhibiting effect of MFs on the function of membranes.

BIOPHYSICAL ACTION OF MICROWAVES

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Theoretical and experimental investigations of biological action of radioemissions show that it is rather varied and defined by intensity, duration, wavelength range, modulation-time characteristics and other parameters of an active electromagnetic field (EMF). Electrical, magnetic and other properties of irradiated objects and systems as well as conditions of influence are also of great importance [1,2,3]. The effects of action of radiofrequency electromagnetic radiation (EMR) essentially depend on EMF frequency characteristics and in many respects they are formed by primary and subsequent biophysical and biochemical ways and mechanisms. Therefore the study of the biophysical action of EMF and EMR is highly necessary for proper understanding and practical use of the medico-biological and ecological action of radioemissions and it is also necessary for the solution of problems of electromagnetic safety.

Microwaves - the EMF and EMR of decimetre, centimetre and millimetre of waves ranges affect all living systems. Investigators have studied, and now they use in practice, the «thermal» effect of microwaves which is observed under the action of electromagnetic fields of comparatively large intensity (10 mW / cm^2 and more). The basic mechanism of the thermal effect is the temperature increase of the irradiated object due to a considerable amount of heat emitted. Microwave heating has a substantial advantage as compared to ordinary heating methods: it may be done rapidly, in measured doses, in the exact spot required and distributed almost uniformly over the whole volume.

Along with the thermal effect, microwaves possess an expressed energetic and energo-informative action which may be decisive under certain conditions. It is called «specific» and is not directly connected with the temperature increase of the irradiated object. Specific influence of microwaves is determined by more delicate and precise biophysical ways and mechanisms of interaction of EMF and EMR with bio-objects and it is connected with corresponding formation processes of energetic, physico-chemical and conformational states of biomacromolecules and molecular systems in the acting electromagnetic field.

We experimentally found a distinct specific effect of microwaves on cell membranes observed at different intensities and other parameters of EMF. Microwaves with the intensity from 0,1 to 1 mW / cm^2 exert a stabilising influence on the membranes of human erythrocytes. Such action is apparently determined by improvement of the interaction between proteins and lipids in the membrane and by stabilisation of biomacromolecular conformational states with the participation of molecules of water, ions and other particles.

Microwaves also exert a similar influence on yeast cells. The changes of growth and development of irradiated yeast culture is observed by research of low-intensity microwave action on morphological properties and fermentative energy of yeasts. The radioemissions exert a sufficient favourable influence at definite values of intensity, duration and modulation. It is expressed by uplifting of viability and better growth of yeast cells and their colonies.

One of the basic mechanisms of the specific influence of microwaves is the selective action of EMF and EMR on biological membranes and other high well regulated structures and systems of living cells and body on the whole [1,4]. Biomembranes possess heterogeneous electrical properties that are determined by their biochemical composition and structure [5]. The surface layers of biological membranes have a higher concentration of electrical charge and comparatively small values of dielectric permeance in comparison with an electrolytic medium. Therefore they possess an expressed ability to selective energetic interaction with microwaves. This interaction in biomembranes is realised with the participation of electrically charged and polarly functional groups and radicals of proteins, lipids, nucleic acids, ions and other components of living systems. The selective action of microwaves is strengthened by synchronisation processes of appropriate oscillators and oscillatory processes of the biosystem in an acting microwave EMF [2,6,7]. It is notable that the molecules of structural (connected with molecular components) water of a living system play an essential role in the specific action of radiation [1,8,9]. A typical frequency of molecules of such water in biosystems is about 10^9 Hz.

We have shown that selective action of radioemission on biomembranes doesn't cause their overheating in relation to the environment at comparatively small intensities of microwaves. However, resonance effects are possible in the irradiated object if time of exposure is much greater than the average period of heat motion of molecules H_2O and if the frequency of acting radiation is close to the proper frequency of oscillated molecules [9]. In this case the resonant particles can be greatly swung (to heat them sooner than the electrolytic medium is heated). It is

most probable that in microwave range the molecules of structural water, hydrogen atoms, OH groups and other oscillators will appear as resonant particles.

At the molecular level we have shown the selective action of microwaves on examples of conducting physico-chemical process of complex formation in the system of the organic PAR - Cr^{3+} reagent and of the biophysical saturation process of the whole stabilised donor human blood with oxygen (oxygenation). Both processes were realised in a UHF electromagnetic field at ~21 cm wave [1]. The results of the conducted researches have shown that the oxygenation in microwave EMF at the temperature of 37°C takes place with visible modifications of protein-haemoglobin absorption coefficients in the red and infrared ranges of the light radiation spectrum. Greater differences are noted in the infrared range of wavelengths of the registering radiation.

Interaction of an organic agent with chromium gives coloured PAR - Cr complex in PAR - Cr^{3+} system. But its formation is prevented by the insignificant reaction ability of Cr^{3+} at room temperature which is caused by the formation of aqua-complexes of that ion in water solutions. Therefore, to improve the reaction ability of Cr^{3+} and to obtain the PAR - Cr complex quickly enough, the reaction mixture is heated and boiled for 5 minutes. The action of microwaves activates the chromium ion at a comparatively small temperature, close to room temperature. Thus an EMF provokes a much greater issue of the reaction product at 42°C than even by boiling the reaction mixture without irradiation. This is a very convincing manifestation of the non-thermal specific action of microwaves.

On the whole, according to our, and other Russian investigators', data and the data of other investigators abroad, the biophysical action of microwaves is realised with an active participation of three mechanisms generated in a living system. These are:

- selective action of microwaves on the biological membranes and other highly-organised components and systems of living cells and body, on the complex formation processes and fermentative activity;
- synchronisation of oscillatory processes of irradiated systems in active EMF;
- resonance phenomena in irradiated objects and systems.

These mechanisms participate in the formation of different biological effects of microwave action including the effect of radio sound - direct acoustic reception of microwaves [10].

Determination of the dynamics of electron-conformational transitions and new approaches to physical mechanisms of biomacromolecular function offer the possibility of simultaneous realisation of processes of mass transversion, energy transformation and information transfer in a single act [11]. There is a close correlation between the functional activity of biopolymers and their internal agility. The quick and comparatively small fluctuations peculiar to the functional groups of biopolymers and molecules of structural water exert substantial influence on the conformation and functional state. From this point of view, the action of microwaves according to the above-mentioned mechanisms may cause alterations of the fluctuation dynamics of molecules in biomembranes and other supramolecular systems and determine the specific action of EMF and EMR.

Depending on the parameters of the acting field, the influence of microwaves may be harmful or favourable. In certain specially selected modes, microwaves of man-made (technical) sources exert a highly useful, beneficial influence which could be effectively used in biology, medicine and other fields [2, 12, 13, 15]. Low-intensive EMF and EMR (0,1 mW/ cm^2 and even lower) will be of use in many respects.

According to A. S. Presman's and other authors' data, the biological activity of microwaves may be observed at intensities compared with those of EMF of natural sources in the biosphere of the Earth. Besides, from our point of view, radioemissions of such sources exert a favourable, stabilising biological influence. The new experimental data obtained confirm the truthfulness of this conclusion: low-intensive microwaves at ~21 cm and ~18 cm wavelength (typical of discrete sources of the celestial sphere) exert a sufficiently stimulating, favourable effect on the growth, development and productivity of cultivated plants [15]. Thus, research on the action of UHF electromagnetic radiation with the intensity of 500 $\mu W/cm^2$ for momentary irradiation of soaked seeds of maize and whole onions showed that in the beginning of vegetation the growth and development of irradiated plants are slightly retarded compared to non-irradiated ones; yet, as they grow, a substantial activation of living processes of the plants exposed to microwaves occurs. A favourable, stimulating action of UHF is observed, especially well expressed at two frequencies of the 18 cm radiowave range: 1665 MHz and 1667 MHz, that are typical of compact cosmic sources of maser radiation.

On the whole, correct definition of specific biophysical ways and mechanisms of microwave action is very important today. It can really substantially contribute to effective decision-making concerning electromagnetic safety problems and purposeful use of microwaves for medical and other practical aims [14, 16].

According to the information of foreign and Russian investigators, the electromagnetic fields and radiations of man-made (technical) apparatus and systems exert an unfavourable influence on human health and components of the biosphere. To our mind, such effects are to a large extent conditioned by not quite proper use of technical sources of EMF and EMR and by non-observance of necessary safety measures.

Determination of ways and mechanisms of biophysical action of microwaves is also of great importance for the establishment of the role of modulation in the biological action of EMF and EMR. Nowadays different kinds of modulation are used in development and operation of many radiotechnical apparatus and systems in communication, broadcasting, television, radiolocation, astronomic research etc. However, the methods of hygienic rate setting and standards in force do not yet cover «the influence conditions of EMR with complicated physical characteristics in particular, as applied to specific modes of amplitude and frequency modulation» [17]. It was only recently, that the US National Council on radiation protection (NCRP) made a real step in the present direction: it recommended a 5-fold decrease in the standards if the carrier frequency of EMF is modulated with the depth of 50% and larger at the frequency of modulation from 3 to 100 Hz. This recommendation found its expression in the US standard IEEE C 95.1 (1991).

At the same time, as shown above, according to the theoretical and experimental data obtained by academician N. D. Devyatkov, us and other scientists, the normalising, favourable and even stimulating, therapeutic action of microwaves of technical (man-made) sources with certain parameters of the acting field [18] was convincingly confirmed. Therefore, the medico-biological research (effective and purposeful use of electromagnetic fields and radiation, including microwaves, for the preservation and improvement of human health and improvement of the ecological situation) must be given a much higher priority. This was quite definitely stated at the recently held 2nd Congress of the European Bioelectromagnetics Association [19]. However, while the technical side sees a continuous improvement of sources and equipment, the medico-biological and ecological aspects of EMF and EMR action need further large-scale research and study, for which necessary funds must be provided. Such work will provide the

possibility of concretization and effective use of the interesting primary and subsequent biophysical and biochemical effects of microwave action. They include: [2, 20]: interaction of EMF and EMR with fields of living systems and their components; electrical and magnetic polarisation and saturation in strong fields; quantum effects, relaxation of particles and resonance phenomena; synchronisation in acting electromagnetic fields; energetic and energo-informational interaction of microwaves with highly-organised biomacromolecules and supramolecular systems; change of kinetics of the complex formation processes and fermentative activity, other processes and reactions in living systems; selective action of microwaves on biomembranes, nervous system and analysers, on the emotional state and behaviour of living organisms, including humans, etc. The degree of expression and character of these effects depend on frequency, energy, modulation and other parameters of microwaves, properties of irradiated objects and systems, on the conditions of irradiation and availability and possibility of combined action of other factors too.

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DOSE DEPENDENCIES IN BIOEFFECTS OF EXTREMELY HIGH PEAK POWER MICROWAVE PULSES

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Introduction

Tissue heating by moderate and high microwave intensities is the established mechanism of most known biological effects of this radiation. "Thermal" bioeffects can usually be predicted from the rates of energy absorption and heat dissipation in exposed specimens. However, it is not clear if this dose-based approach is valid for irradiation with brief, extremely high power pulses (EHPP). At peak specific absorption rates (SAR) as high as kilowatts per gram, high instant values of the electric field, thermoelastic stress, or other mechanisms could produce tissue damage, even if the time-average SAR is low and general heating is negligible. Safety guidelines based upon the average absorbed or incident powers do not necessarily address the potentially harmful effects of EHPP, making it imperative that the possibility of such effects be investigated.

The present knowledge of EHPP bioeffects is limited and contradictory. In some studies, EHPP disrupted cognitive function and significantly decreased physical endurance in rats without increasing the body temperature (Akyel et al., 1992; Raslear et al., 1993). In other studies, which employed somewhat different EHPP parameters, all behavioral and physiological changes observed in exposed rats and monkeys could be attributed to heating (D'Andrea et al., 1989; Klauenberg et al., 1990; Akyel et al., 1991; Jauchem and Frei, 1995).

The present work tested the applicability of the dose-based approach in exposure to brief EHPP trains. Using an isolated heart preparation model, we compared bioeffects of EHPP trains with (1) a constant number of pulses per train, but different interpulse intervals, and (2) different numbers of pulses per train, but a constant interpulse interval. Microwave heating was linearly proportional to the number of EHPP per train, but did not depend on the interval between them.

Methods

We employed an in-waveguide exposure setup capable of creating peak SAR of up to 400 kW/g in small samples (100-200 μl). Square microwave pulses

(9.5 GHz, 1 μs width, 100-115 kW) were produced by an EPSCO Model MH300 system with an MF-IM65-01 RF plug-in into a WR90 waveguide (22.86 x 10.16 mm). Incident and reflected powers in the waveguide were measured via directional couplers by HP 438A and HP 435B power meters with HP 8481A power sensors. Microwave pulse trains were triggered externally from a Grass Instruments S8800 stimulator. The shape of microwave pulses was monitored via an HP 432 detector on a TEK 2430A digital oscilloscope.

The exposure cell at the end of the waveguide was separated by a quarter-wave matching plate and filled with 6 ml of Ringer's solution containing (mmol/l): NaCl, 103; KCl, 1.0; $NaHCO_3$, 0.6; $CaCl_2$, 0.9; pH 7.2-7.4. The waveguide walls in the exposure cell were covered with a lacquer to prevent its electrical contact with the solution.

With this setup, SAR in the solution decreased exponentially with increasing the distance above the matching plate. SAR as a function of this distance was calculated according to Chou and Guy (1978) and verified by direct measurements. At 25°C, calculated SAR equaled 610, 304, 145, and 69 kW/g per 100 kW of transmitted power at 0, 1, 2, and 3 mm above the matching plate, respectively. Within the depth of the solution in the exposure cell (about 25 mm), the radiation was absorbed almost completely, thus requiring no additional protection of the personnel or laboratory equipment.

Direct SAR measurements were performed with a microthermocouple (MTC) made of 25-μm copper and constantan wires (Omega Engineering, Inc.) The MTC was covered with lacquer for insulation and fixed in a custom-made holder in a micromanipulator, above the exposure cell. Temperature readings by the MTC were recorded on a PC using a universal amplifier (Gould 5900 frame) and a BIOPAC MP100 data acquisition system.

Virtually instant response of the MTC to temperature changes made it possible to record a temperature plateau for a period of 200-600 ms after a single EHPP or a brief EHPP train. Within the duration of this plateau, heat dissipation could be disregarded. Therefore, the peak SAR could be calculated from the level of this plateau and known duration of the microwave pulses, despite EHPP-induced recording artifacts during the train itself. More detail on this method and its validation can be found in a separate publication (Pakhomov et al, 1998). Calculated and MTC-measured SAR matched well for various MTC positions in the exposure cell, output powers, numbers of pulses, etc. In all cases, measured SAR was 1.1-1.8 dB below the theoretical one; this small difference was likely to

result from imperfection of power meters and/or of the theory, rather than from inaccuracy of the temperature measurements.

An important detail established by the MTC thermometry was that the maximum microwave heating (i.e., the level of the plateau on the heating curve) was linearly proportional to the number of EHPPs in a train, but, within certain limits, it did not depend on the interpulse interval (Fig. 1).

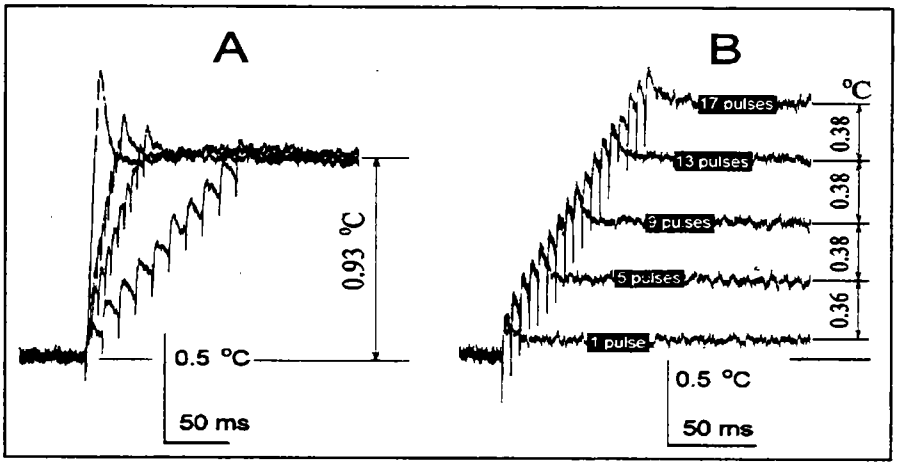

Fig. 1. Heating dynamics under exposure to EHPP trains (1 μs pulse width, 9.5 GHz, 400 kW/g peak SAR). Spikes during the ascending portion of the curves (artifacts) correspond to EHPP pulses. **A**: 10-pulse trains with different interpulse intervals (1, 3, 5, and 13 ms). Regardless of the interpulse interval, maximum microwave heating (the plateau level) is 0.93 °C. **B**: Trains including different number of pulses, but with a constant interpulse interval of 5 ms. Maximum microwave heating is linearly proportional to the number of pulses in the train. Heating by a single pulse is about 0.09 °C (not shown); each increase of the train by 4 pulses increases heating by about 0.38 °C. For these temperature measurements, we used 20- or 50-ms averages of the amplified voltage from MTC.

Dose dependencies of EHPP effects were studied in isolated, spontaneously beating sections of the cardiac sinoatrial area of the frog *Rana catesbiana*. The sections were of irregular shape, a few millimeters wide and long, and less than 1 mm thick. Peak SAR measured in saline at the position of the geometrical center of the preparation (i.e., about 0.5 mm above the matching plate) ranged from 270 to 310 kW/g. Maximum heating of the preparation was 0.08-0.09 °C per one EHPP; for trains consisting of n pulses, the maximum heating was n times greater.

The endpoint in these experiments was the immediate change in the duration of individual inter-beat intervals (IBIs) after delivery of a single EHPP train. Local currents, induced in the surrounding solution by beats of the preparation, were recorded by a BIOPAC MP100 data acquisition system using artifact-free electrodes (glass capillaries filled with the same solution). After positioning of the preparation at the bottom of the exposure cell, it was allowed to stabilize for 30-60 min. While recording a stable beating rhythm, we applied a train of microwave pulses (it always fell within a single IBI). The exact time when the EHPP train was applied was recorded on a separate marker trace, concurrently with the preparation beats.

Ten IBIs immediately preceding the exposure were assigned numbers from -10 to –1; the IBI coinciding the exposure was No. 0, and the next ten intervals were numbered from 1 to 10. The exact duration of each of these 21 IBIs was measured automatically. A record of 21 IBIs which included one exposure or sham exposure was considered as a single experiment. Experiments with initially unstable rhythm (more than ± 2% variation of individual IBIs before the EHPP train) were noticed for analysis and discarded.

Though being very stable in each particular experiment, the IBI duration ranged considerably (from 1 to 3.5 s) from one preparation to another. Hence, the raw data from different experiments had to be normalized before averaging, so the duration of the first (-10th) IBI in each experiment was taken as 100%.

The same preparation was usually used in several different experiments, allowing at least a 15-min interval between them for function recovery and stabilisation. Different regimens of microwave exposure were randomized with sham exposures. For a sham exposure, a waveguide switch was used to block microwave propagation to the exposure cell, otherwise all conditions were kept the same as with actual exposures. All experiments were performed at a room temperature of 24-27 °C.

Results

Series 1. In 87 experiments on 20 preparations, we studied the effect of 5-pulse EHPP trains. The interpulse intervals were 1, 5, or 25 ms, yielding the entire train durations of 4, 20, and 100 ms, respectively. Microwave heating did not depend on the interpulse interval and was the same for all these regimens (0.4-0.45 °C maximum). There was no special synchronization of the train onset with the preparation beats, but experiments with the EHPP train coming during the first and the second halves of an IBI were processed separately.

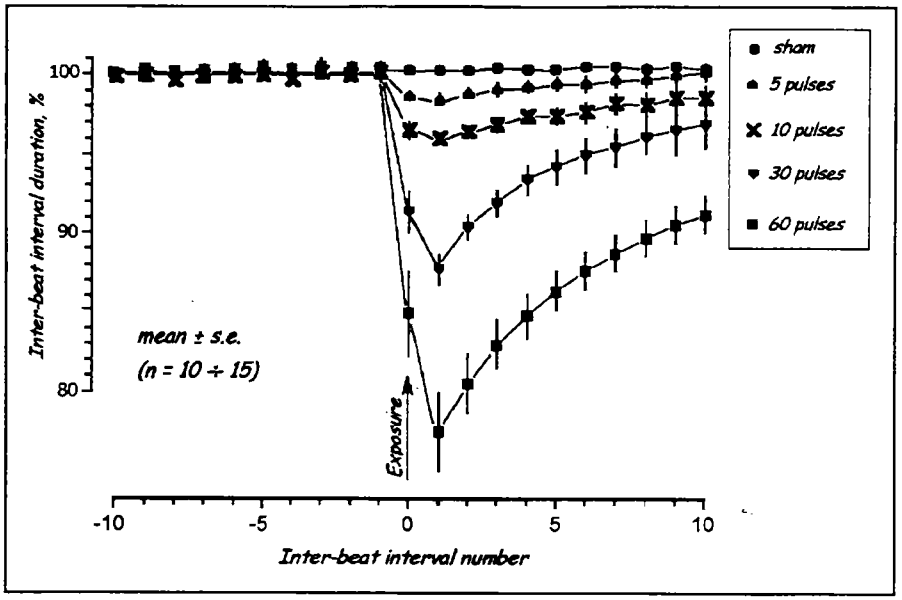

Fig. 2. Changes in the inter-beat interval (IBI) after exposure to a 5-pulse EHPP train (9.5 GHz, 1μs pulse width, 270 to 310 kW/g peak SAR). The train is applied during the first (**A**) or the second (**B**) half of the interbeat interval No. 0. Sham-exposed group is the same for **A** and **B**; *n* is number of experiments in each group. IBI decrease immediately after exposure is significant in all the groups (at $p<0.05$ or $p<0.01$). Differences between the exposed groups are not statistically significant.

In 100% of the experiments, EHPP irradiation immediately decreased the interval between beats, followed by a gradual recovery to the initial level. The averaged data are presented in Fig. 3, A and B. Though maximum effect was only 1.5-2.5%, it was significant at $p<0.05$ or $p<0.01$ (Student's *t*-test) compared with either the pre-exposure level or sham controls. As one could expect, the EHPP-induced changes in the beating rate developed slightly later in preparations that were exposed later within the IBI (namely, during the second half of the IBI, Fig 3, B). However, this was the only noticeable difference between the exposed groups, and the effect showed no dependence on the interval between pulses in the EHPP train.

Some authors (Tigranyan, 1986) reported that excitable tissues (e.g., isolated nerve and heart of the frog) are particularly sensitive to microwave pulses

within a certain period during or after excitation. In our experiments, the EHPP train fell within various intervals after excitation (i.e., a beat), but no "critical periods" were observed. Furthermore, in six experiments when the EHPP train coincided with a beat (too few cases for statistical analysis, so they were not considered above), the exposure effect was practically the same as in other experiments.

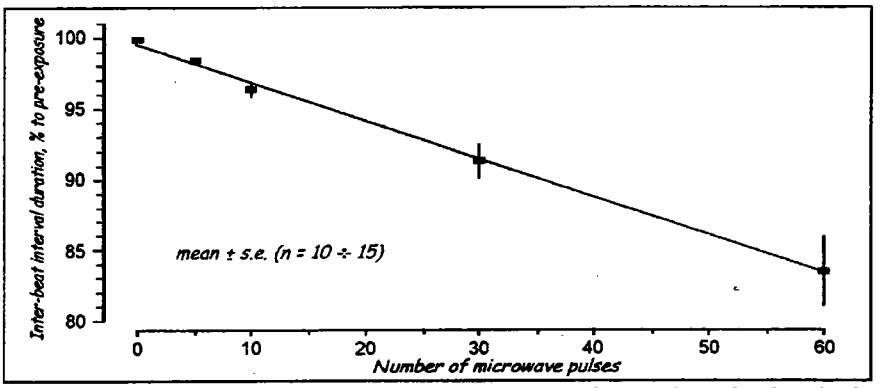

Fig. 3. Dependence of the inter-beat interval change on the number of pulses in the EHPP train. The data for exposure to 5-pulse trains are imported from Series 1, all other data are from Series 2. The interval between EHPP in the train is 1 ms; see Fig. 2 for more exposure detail. Differences between all the group are significant at $p<0.01$ (for datapoints immediately after exposure).

Series 2. In this independent series of 65 experiments (18 preparations), the interval between pulses in EHPP train was fixed at 1 ms, and the trains consisted of 10, 30, or 60 pulses. The trains were always applied within the first half of the IBI. In most cases, the exposure immediately decreased the IBI proportionally to the number of pulses in the train, followed by a gradual recovery (Fig. 3) The maximum decrease (by 15-20%, $p<0.01$) was caused by 60-pulse trains. The maximum heating was linearly proportional to the number of pulses in the train, and so was the response of the preparation (Fig. 4). However, in the remaining experiments (about 15%), irradiation produced the opposite effect: it halted the preparation contractions, delaying the next expected beat for a period from 0.5 s to more than 100 s (Fig. 5). This paradoxical response occurred in 2 out of 17 exposures to 10 pulses, 3 out of 16 exposures to 30 pulses, and in 6 out of 17 exposures to 60 pulses; it was never caused by sham exposures or 5-pulse trains in the preceding set of experiments.

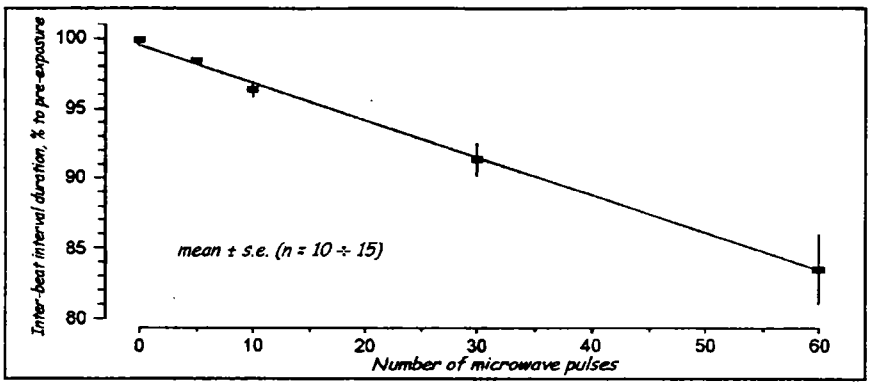

Fig. 4. Duration of the inter-beat interval coinciding the EHPP train versus the number of pulses in this train. (The same data as in Fig. 3). See Figs. 2 and 3 for more detail.

Discussion

A common way to judge whether exposure effects are or are not caused by heating is the comparison of reactions to microwave and equivalent conventional heating. However, this comparison would only be accurate if the dynamics of microwave and conventional heating are the same. In EHPP experiments, the instant heating rate (during a microwave pulse) reaches almost 100,000 °C/s, which cannot be matched by a conventional heating. In this situation, dose-response curves can be used for qualitative analysis of the role of heating in biological effects of EHPPs.

It is well known that a subtle or moderate heating increases the pacemaker rhythm (shortens IBI) in isolated frog heart preparations (Yee et al., 1986; Chernyakov et al., 1989; Pakhomov et al., 1995). Consistently, in most of the experiments described above, EHPP exposure produced an immediate decrease in the IBI duration. When the EHPP train was varied in a way that kept the absorbed dose and microwave heating constant, the biological effect remained constant as well (Series 1). At the same time, the IBI decrease was linearly proportional to the number of EHPPs per train, which was the parameter that determined the absorbed dose and heating (Series 2). This pattern of reacting to EHPPs is in agreement with the thermal mechanism of EHPP bioeffects.

One should note that beats in our preparation could only be induced by stimuli coming from pacemaker structures. Therefore, any IBI decrease reflected

an increase in the pacemaker rhythm. However, a temporary cessation of beats or IBI increase did not necessarily arise from a change in the pacemaker rhythm. Most likely, it was caused by a temporary uncoupling of contractile structures from the pacemaker, and some experimental records prove that it was the case indeed. For example, in the experiment shown in Fig. 6, we concurrently recorded large and small beats, which were produced by two groups of contractile fibers. Before exposure, small and large beats were nicely synchronized, indicating that they were driven by the same pacemaker, but the large beats were elicited by every other stimulus from the pacemaker. This omission of pacemaker stimuli is not uncommon, and indicates somewhat imperfect coupling of the respective contractile structures with the pacemaker. EHPP exposure halted the large beats, but the small beats continued uninterruptedly and increased their rate. Hence, the cessation of the large beats was caused by uncoupling and not by deceleration of the pacemaker. Though such analysis was not possible for every experiment with IBI increase after exposure, one can reasonably suppose that the impairment of coupling was responsible for this effect in other cases as well.

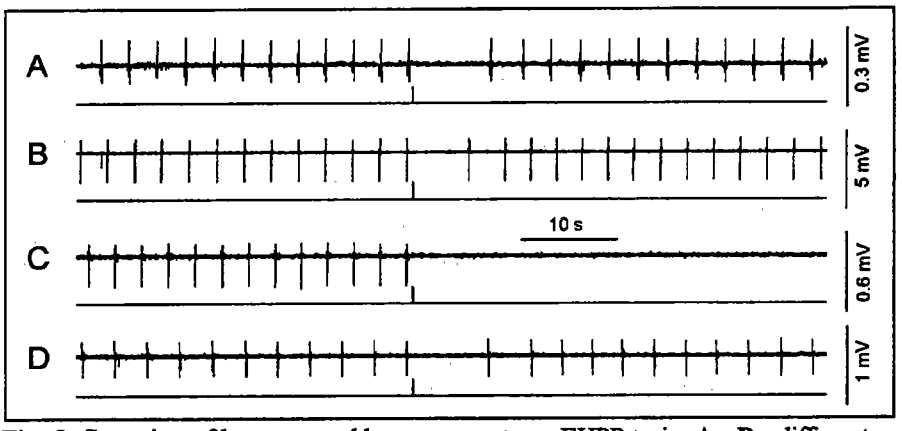

Fig. 5. Cessation of beats caused by exposure to an EHPP train. **A** - **D** - different preparations of the sinoatrial area of the frog heart. Upper traces, spontaneous beats of the preparation. Lower traces, marker of microwave exposure (9.5 GHz, 1 μs pulse width, 1 ms interpulse interval, 270 to 310 kW/g peak SAR); a single train of 10 pulses (**A**), 30 pulses (**B** and **C**), or 60 pulses (**D**).

Though uncoupling could be caused by a thermal effect of exposure, possible specific EHPP effects could not be discarded either. The temporary cessation of beats occurred only in a small percent of experiments, and the total number of observations was insufficient to make a prudent judgement. As concerning the dose dependencies of EHPP effects on the pacemaker rhythm, they

were fully consistent with the thermal mechanism of microwave action. On the whole, the present experimental data are not suggestive of any mechanisms of EHPP bioeffects other than ordinary heating.

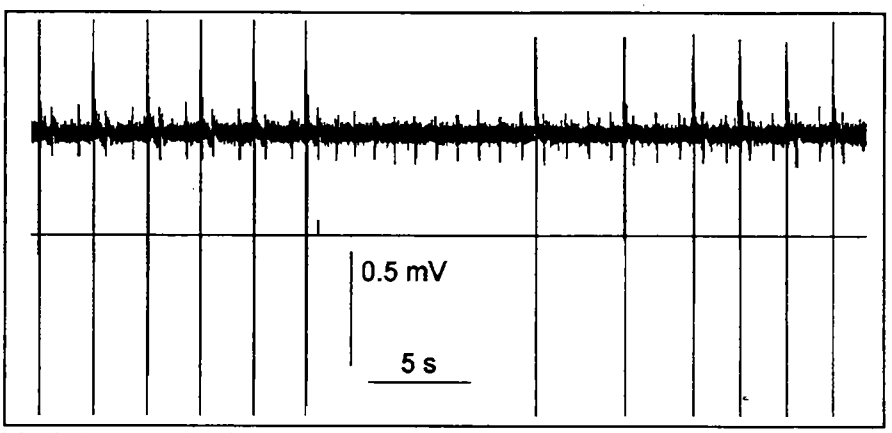

Fig.6. An example of a "dual" response to EHPP irradiation. Marker (the lower trace) indicates the moment of exposure to a 60-pulse train. This exposure increased the interval between large beats and shortened the interval between small beats. See Fig. 5 and text for more explanation.

Acknowledgements

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COMPARATIVE BIOLOGICAL EFFICIENCY OF CONTINUOUS AND PULSED RADIOFREQUENCY ELECTROMAGNETIC FIELDS

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The problem of electromagnetic pollution in the environment has arisen as a result of wide development of specialised means of transfer of energy and information, bringing a significant contribution to the natural electromagnetic background. However, despite more than obvious importance of this field, some aspects of the evaluation of biological efficiency of radiofrequency electromagnetic fields (EMF) are still far from being resolved. It especially concerns EMF with various kinds of modulation, in particular pulsed, where a uniform concept of the specific character of its action in comparison with continuous radiation is still absent. The study of biological efficiency of modulated EMF is considered rather important, as besides the purely scientific importance it can also be of practical interest, in particular, for refining the hygienic specifications, promoting better regulation levels of non-ionising radiation in the environment.

According to the existing notions, the influence of EMF can be exerted on the entire biological system, as well as on separate levels of its Organization. Correct placement of EMF primary action in the complex hierarchical structure of any biological system is a difficult and not yet quite solved problem. However, if EMF with equal power characteristics or, that is even more essentially, at identical specific absorbed rate (SAR), but with a different structure of the signal, causes opposing reactions in the same biological system, this fact alone is enough to indicate that the action mechanisms involved may be different. An analysis of the existing literature sources, which present experimental materials of comparative biological EMF action with continuous and pulsed modes of radiation at identical bearing frequencies, SAR values, the same objects and conditions of experiments, has revealed the following ratios. Pulsed EMF radiation mostly resulted in a greater biological effect, than continuous one, and in a smaller number of cases - did not differ in magnitude or direction of responses. Among all the analysed sources, only in one case did EMF in a continuous mode produce a more expressed action, than in pulsing. One can assume that greater unification of the methods of irradiation and, especially, of those of dosimetry, as their absence considerably reduces the chances of an adequate comparison of the results obtained in various laboratories, would tilt the balance still more in favour of the prevailing effect pulsed radiation. Thus, according to the data in the literature, the biological action of pulsed EMF either exceeds the continuous one in efficiency or produces the

same result, which gives good grounds to assume the existence of different mechanisms of interaction with biological objects.

Investigating, with the help of numerical modelling, the absorption and distribution of EMF pulse energy in dielectric media, Moten et al. [1], as well as Albanese et al. [2], and Gandhi [3], have shown, that a pulsed field is characterised by a greater depth of penetration, than a continuous one, at identical bearing frequencies and average power density. This process is especially expressed at shorter frontal duration and greater spectral width of an EMF pulse, and even in biological media with an increased water content, when attenuation of the maximum harmonics is more intensive, than that of the lowest.

Within the framework of this problem, comprehensive investigations, aimed at comparative study of EMF influence in continuous and pulsed modes on some functional animal and model systems were conducted. The experiments were conducted for radiation conditions in a far zone of a TEM wave source, which were simulated in a TEM cell, creating a standard field in the absence of distortions in its structure in the working volume and enabling one to define determine the SAR of the investigated object [4]. In all researches irradiation was conducted at identical carrier frequencies for continuous and pulsed EMF and durations of pulses at pulse-repetition frequencies of 16; 32 and 64 Hz and E - polarisation. An indispensable and strictly controlled condition was the maintenance of the average power density and identical SAR for all modes of irradiation and experimental series. The SAR values lay within the 0,006 W / kg up to 0,1 W / kg limits; radiation time lasted from 30 minutes up to round - the - clock action for a month. Reactions of CNS (behaviour), cardiovascular system (ECG in vivo, haemodynamics of Langendorph isolated heart of a warm - blooded animal), blood (cytomorphological analysis of peripheral blood and bone marrow, erythron condition), unspecific immunity (serum blood complementary activity) and endocrine system (adrenal cortex and thyroid gland function) were investigated. In the in vitro conditions the study was conducted of blood serum (complement activity) and erythrocytes suspension (fragility).

CNS reactions to one-time 6 hour EMF exposure (SAR 0,006 W / kg) were characterised by a reliable increase of the emotional threshold with passive-defensive behaviour and a decrease of vertical activity in orientation and search reactions of rats only in the pulsed mode with the pulse-repetition frequency of 16 Hz. For pulsed radiation with the pulse - repetition frequency of 32 and 64 Hz and continuous EMF, responses of the animals showed confident differences from the control values, though one observed a tendency to activation in the continuous mode. With round - the - clock 30-day exposure to pulsed EMF (SAR 0,012 W/kg

) with the pulse - repetition frequency of 16 Hz , the rats' behaviour was characterised by a reliable decrease of their sensory susceptibility threshold and increase in the horizontal activity of the animals on the 11th day of exposure, whereas for other measured parameters and exposure modes no changes were observed. An analysis of the changes in behaviour of the animals in response to EMF radiation in the pulsed mode in comparison with the continuous one, supports the assumption that the specific character of pulsed radiation causes an aberration of behaviour reactions at the beginning of exposure, whereas with continuous exposure this occurs later.

No changes were seen in the rhythm and size of the shock volume of the left ventricle upon exposure to EMF during 30 minutes (SAR 0,006 W / kg) in continuous and pulsed modes in isolated rat hearts, though a tendency to bradycardia was observed at the pulse-repetition frequency of 16 Hz. It appears that the EMF intensities used in the experiments were too low to cause changes in the activity of an organ possessing a large reserve functional potential.

EMF influence, in both continuous and pulsed modes, on the condition of the blood system was observed both at the whole body level with round - the - clock EMF exposure of rats during 30 days (SAR 0,012 W / kg), and in the in vitro experiments. The dynamic analysis of changes in the peripheral blood and bone-marrow of the subjects has shown that, from the 20th day of EMF exposure with the pulse-repetition frequency of 16 Hz , the reaction is observed with both the leukocyte and erythroblast shoots of the bone - marrow resulting on the 30th day in hypoplasia of the bone - marrow, erythrocyte cell macrocytosis and amplification of proliferation processes. At the same time no such changes in the erythrocyte shoot were found, though there some grounds for the assumption that regenerative processes would develop later. Comparative researches on EMF radiation during 30 minutes in continuous and pulsed modes with the pulse - repetition frequency of 16, 32 and 64 Hz on the erythrocyte fragility of rabbit blood in vitro, were unable to establish reliable distinctions between the control and experimental samples.

The researches of reactions on the part of the complement system in rabbit blood serum at daily 6 hour EMF radiation (SAR 0,02 W / kg) showed a reliable reduction of complement activity on day 5 and a later increase on day 9 days in the control values if the mode with the frequency of pulse recurrence of 16 Hz was used. In the experiments in vitro it was established that a 30 minute EMF exposure reliably reduces the serum complement activity of the subject at the pulse - repetition frequency of 16 Hz, whereas in the continuous mode and at other frequencies for pulsed modulation no reliable differences from the controls were

observed. It is notable that in these results one observes a clear-cut correlation between the effect and the peak power density values depending on the pulse-repetition frequency at the identical, in all the modes used, power density and SAR.

For evaluation of the animal endocrine system exposed to EMF we assessed: gluco - and mineralcorticoid function of adrenal cortex gland (corticosterone excretion, ions Na and K), thyroid gland activity (thyroxin and triiodothyronine of plasma blood) and anabolic function (testosterone excretion). Dynamics of corticosterone excretion levels and Na / K ratio in rats exposed to EMF (SAR 0,006 W /kg) reliably differed from those in the control group by its maximum increase on day 10 of the experiment in the pulsed mode with the pulse-repetition frequency of 16 Hz. The contents triiodthyronine and thyroxin in the rabbit plasma blood of animals with similar parameters of EMF exposure (SAR 0,02 W / kg) during the experiments demonstrated statistically uncertain variations, among which it was possible to specify an expressed tendency to the decrease of triiodthyronine in the first days of exposure to pulsed EMF. The anabolic activity showed good correlation with the changes in animal weight, the maximum reliable changes were observed with round - the - clock 30-day EMF pulsed radiation (SAR 0,012 W / kg) with the pulse - repetition frequency of 16 Hz, from day 2 till day 16 of the experiment, thereafter a return to the reference values was observed.

Evaluating the results obtained as a whole, it is necessary to note, that the sensitivity of various functional systems to EMF action in both continuous and pulsed modes is substantially different. Thus, in the investigations conducted the responses of the cardiovascular system, isolated heart, as well as the changes in erythrocytes fragility in vitro, have not shown any reliable differences from the control values at EMF exposure either in the continuous or pulsed modes. However, other experimental data obtained have been more conclusive, and their generalised interpretation can be presented as follows:

Dynamics of responses on the part of the main functional systems of the animals testifies to adaptational - compensating changes with the parameters and EMF exposure applied. The non-linear character of adaptational - rehabilitative processes which proceeded in an oscillatory mode enables one to analyse and forecast both the body responses to the acting factor and to evaluate the factor itself. Though the dynamics of these processes with various parameters is not everywhere the same, the characteristics of EMF biological activity is in this case the structure (sign and amplitude) of the temporary interrelations in the development of adaptational - compensating reactions. From these positions, the EMF effect in the pulsed mode causes an earlier (with a phase displacement

towards the beginning of the exposure) response, than in the continuous mode, the structure of mutual relations of which usually remains constant. Comparing the results obtained with those found in the literature and considering, while evaluating the biological efficiency of EMF, not only the carrier frequency, intensity and time of exposure, but also the structure of the modulated signal, the pulsed mode can be regarded as having a more pronounced effect, than the continuous one. Since in the investigations conducted the only parameter changing with the pulse - repetition frequency at the identical average power density are peak (amplitude) values, it is probably those that play a leading role in the formation of marked biological effects [5]. Thus, with the increase of pulse - repetition frequency (duty cycle reduction) at their constant duration, the biological efficiency of pulsed EMF is reduced, approaching in its extreme values to the continuous, as to strength and direction of responses.

The EMF interaction with biological medium, with the exception of "resonant" and high intensity action, in the first approximation can be considered as linear in the case of non-modulated radiation (sinusoid wave signal), which depends on the field frequency. Vice versa, in the case of pulsed EMF the interaction is initially characterised by non-linearity, determined first by the parameters of the pulse itself (shape, duration of the pulse and its first-transition), and only then by the carrier frequency. Naturally, all the above is true only with equal power characteristics in both modes of radiation. The specific character in the mechanism of action of pulsed irradiation might be most effectively approached from the positions of transformation of energy of an EMF pulse in biological media and systems into mechanical energy. This approach received its development after Frey's discovery of the "radiosound" effect, which was subsequently satisfactorily explained within the framework of the termoacoustical transformation model [6]. It gave Tigranian an opportunity to advance the hypothesis of a mechanical (acoustic) component in the biological action of pulsed EMF, according to which the absorbed energy of a pulse is spent both on simple heating of the object and on excitation of termoelastic waves in it [7, 8]. The advanced concept is no doubt still more attractive, because it does not deny the role of heat as an independent factor of the biological action of pulsed EMF.

The internal cell medium and its environment represent tixotropic systems formed by protein macromolecules, which are characterised by the presence of periodic colloidal structures, whose properties make them occupy an intermediate position between ideally elastic bodies and Newton liquids [9]. Mechanical fluctuations in the biological structures with certain periodicity, due to phase synchronisation of excited waves, can amplify, and thus their transfer function is considered as more informationally valid than the formed heat [10]. EMF pulse-

induced acoustic oscillations, using two main mechanisms, may further be transformed into electrical energy, manifesting itself in biological media as a variable electrical field or current of appropriate frequency. One of them, suggested by Debye, consists in a spatial division in an acoustic wave charge and formation of a vibropotential, arising due to a difference in the weight of ions, charge macromolecules or colloidal particles [11]. The value of Debye's potential, depending in common case on viscosity, temperature and electrical conductivity of the medium, can reach values comparable to those of the membrane potential of most cells. The difference of potentials induced by mechanical fluctuations can arise not only inside a biological medium, but also on the borders of phase sections, for example, at membrane - electrolyte, accompanied by a simultaneous change in the difference of potentials [12].

Concluding the analysis of some mechanisms of interaction and transformation of EMF energy in biological media it is necessary to emphasise their probabilistic character. The ways of transformation of wave processes in such heterogeneous structures, as biological, are complicated are difficult for unequivocal interpretation. The process can be accompanied both by amplification and attenuation of a signal, and by mutual transformation using different mechanisms. However, the expansion of scope of concepts going beyond the conservative framework recognising only "thermal", or only "non-thermal" biological effects of EMF, is at present extremely necessary. Such approaches will probably serve as a bridge, connecting supporters of EMF thermal action EMF and their opponents who insist on the specific nature of mechanism of interaction.

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LONG-TERM EFFECTS OF RADIOFREQUENCY RANGE ELECTROMAGNETIC FIELD EXPOSURE

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The problem of long-term biological effects of radio-frequency electromagnetic fields has not been adequately studied yet. To develop research in this field a complex clinical and hygienic experimental study of low intensity radio-frequency electromagnetic field effects was carried out.

Medical examination of 72 male workers occupied in radio-transmitting communication equipment regulation and 45 controls was performed. The third group comprised 18 individuals previously (10-15 years ago) exposed to electromagnetic field (EMF) effects. The average age in the groups was 36.8, 34.6 and 33.2 respectively. The power exposure in the major group workplaces did not exceed maximum permissible levels. The working conditions were characterised by the following features: variability of EMF intensities, generation frequency, signal modulation, exposure localisation and exposure duration. The analysis of the pathology pattern in the dynamics of employment duration revealed cardiovascular system diseases and gastrointestinal tract diseases accompanied by central nervous system disturbances in EMF-exposed workers at the early stage of their employment. Gerontological effects are known to belong to the long-term effects group. Multiple pathology is one of the basic concepts in geriatrics signifying the body ageing. Early development of age pathology (cerebral atherosclerosis, cardiosclerosis, hypertonic disease) gives the same evidence. Furthermore, early ageing is characterised by limited body adjustment. Thus, psycho-physiological examination of practically healthy individuals of the major group elicited reduced or broken relationship between psychological and physiological indicators on the one hand, and strengthening of inter-physiological relationships, on the other hand. It indicates the decrease of body compensatory capacity in EMF-exposed persons without clinical manifestations. Electroencephalographic study revealed the activity decrease of the right hemisphere (5).

The decrease of A and M immunoglobulin levels, lymphocyte number, segmented neutrophils levels was seen in EMF-exposed workers in the dynamics of employment duration. It points to the decrease of body immunological reactivity. This might probably cause the increased level of acute respiratory infections, influenza, angina, and pneumonia in the major group subjects. A decrease of the body immunological functions is commonly observed in an ageing body. The lipid metabolism changes reported in the major group subjects

undoubtedly contribute to the ageing of the body. Thus, b-lipoproteids level was significantly higher in the major group (P< 0,001). The above-mentioned changes are reported in the early years of employment (over 5 years). Numerous researchers who studied clinical manifestations of the involved agent noted this fact. (1,2,3.)

Biochemical blood analysis findings in EMF-exposed workers showed SH-group decrease and disulphide group concentration increase. Ageing is known to be accompanied by progressive disulphide groups accumulation (4).

Pituitary-gonadal system function changes were registered in the major group in the dynamics of occupational employment duration. It was manifested in the decrease of blood testosterone and pituitary luteinizing hormone levels and in the increase of follicle-stimulating hormone (FSH) level. As reported by F.F. Frol'kis, reduced production of some pituitary hormones and increased production of others (e.g. FSH) indicates the hypothalamic control disturbance, which is inherent in ageing body.

Thus, development of pathology typical of EMF exposure, correlation of pathological changes with occupational employment duration, absence of aggravating effects allow one to consider the etiological relationship between health disturbances of equipment adjusters and modulated RF EMF exposure valid. It may also be concluded that the development of premature ageing syndrome is one of the clinical manifestations of modulated EMF exposure effects. Limited body adaptation capacity, increased disease incidence, significantly premature development of age pathology, early lipid metabolism disturbance, reduced hormonal gonad function and reduced immunological reactivity, character of changes in the thyol disulphide system, give evidence of accelerated ageing rates.

High prevalence of central nervous and cardiovascular system function disturbances were revealed in the third group subjects (previously exposed to EMF). The astenovegetative syndrome and vegetative dysfunction were diagnosed in 14 subjects out of 18; neurocirculatory dystonia of hypertonic and cardiac type, hypertonic disease were diagnosed in 7 subjects. Increased b-lipoproteid blood content, reduced SH-group concentration, reduced A and M immunoglobulin and testosterone levels were also seen in this group.

To clarify the occupational factor contribution to the revealed changes 5 series of experimental studies were carried out on male rats. Animals were exposed to modulated EMF with 4, 13, 22 MHz frequencies and 500 V/m and 300 V/m intensities for 2 months. Daily exposure was 2 hours. Individual and typological

animal features were taken into account in bioeffect assessment. The study revealed the involved factor effect on the central nervous system which was manifested in altered animal behaviour (their activity decrease or increase). Reticulocytes and lymphocytes number decrease in peripheral blood was reported. Biochemical blood studies showed testosterone and leuteinizing and follicle-stimulating hormone level changes, thyol disulphide system disturbances. Male rats were found to have spermatogenesis rhythm impairment, degenerative and dystrophic testicular changes, increased level of chromosome aberrations in lymphoid bone marrow cells, increased abnormal spermatozoids incidence . Pattern and degree of manifested changes depended on exposure regime (carrier frequency, EMF intensity level) and on individual and typological animal peculiarities. Exposed male rats offspring of the first generation was shown to have high embryonic mortality indicating such serious disturbances as dominant lethal mutations. The first and second generations were found to have internal organs pathology, late physical development (body weight and length were significantly less than in the controls). Reduced thymus weight, increased embryonic and postnatal mortality, retarded sensory-motor reflexes development were observed. The above-mentioned disturbances of male animals and their offspring were reported in all series of experiments, that is, the results are highly reproducible.

Experimental studies have confirmed a certain etiological role of the EMF factor in the development of early body ageing and worker's generative function impairment. Clinical and experimental findings revealed that the observed gerontological, atherogenic and mutation effects and the gonad damage effect can be attributed to EMF long-term effects. A long-term effect analysis should by all means be included into the process of EMF hygienic regulation.

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COCANCEROGENIC ACTION OF MICROWAVE RADIATION WITH NONTHERMAL POWER AND NEW METHODS OF THIS EFFECT MODIFICATION

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In recent years the problem of hazardous microwave radiation of non-thermal power for our population has become especially important because of the widespread development of cellular communication with microwave transmitters and also because of the emergence of other antropogenic sources of environment contamination (1). The majority of researchers in searching for the proof of hazardous effects of electromagnetic radiation have focused their attention on estimating carcinogenic risks and obtained rather contradictory data (2-4). At the same time the problem of cocancerogenic action of electromagnetic radiation and particularly microwave radiation with non-thermal power remains practically unexplored, because of the presence in the human habitat of a great number of carcinogenic agents of different degrees of danger. So in practice the cocancerogenic effects of microwave radiation can represent at least the same danger as its own carcinogenic action.

In this connection the aim of our investigation was to try to evaluate, on the basis of experiments on mice, the cocancerogenic action of microwave radiation of non-thermal power , as well as to obtain data on the effectiveness in this case of a new method of weakening late damages to the body (5). Our investigation was conducted on 180 white non-inbred mice (initial genotype of these mice is Swiss), males and females in equal numbers, 3 months old at the beginning of the experiment. The mice were held in plastic boxes (15 animals of the same sex in each groups) and allowed standard food and water ad libitum. We used urethane (5% water solution) as a carcinogen. From the beginning the mice in the experimental groups were injected with urethane solution (0,1 ml i/p, 5 times every 3 days, each mouse during 12 days was injected with 25 mg of urethane). It is known that injection of urethane to mice of this genotype results in tumours on mouse lung, which can come to light after fixation of the lung Buen solution 6 months after the beginning of the experiment. For microwave irradiation of the mice we used a «RANET DMV 20-1» device and an I-1 split antenna, which were installed in a specially shielded chamber without echo. The generator used worked at the frequency of 460 MHz and the value of the falling flow of power in the area where the boxes with the mice were was about 0,40 mW/sq.cm. This power relates to non-thermal action of microwave irradiation. Microwave irradiation of the mice

in the experimental groups was conducted for 2 hours daily, 5 times a week for 12 weeks from the beginning of the experiment (total time of microwave irradiation of the mice during 3 months was 120 hours). In this experiment there were, besides two control groups (with 15 intact males and females mice at the beginning of work), two groups of the same size each subjected to the action of urethane or microwave irradiation, and two more groups where the mice were subjected to the influence of both factors. Another objective of this experiment was to evaluate possible modifying effects on the carcinogenic action of urethane and cocancerogenic action of microwave radiation by a new physical agent - the pulsed electrical field (PEF) with certain parameters. Earlier we found that PEF possesses a prominent biological effect and is capable of weakening the late effects of ionising radiation and other genotoxic agents (5, 6). Exposure to PEF was provided by a specially designed laboratory installation with the following parameters: strength of field - about 10 kV/m, frequencies of electrical pulse - 200 Hz, exposure time - 15 min once a week during the whole 6-month period that the experiment lasted from its beginning to slaughter of the mice (total number of 26 PEF-treatment sessions in the experimental groups). This experiment involved two groups (15 male and 15 female mice respectively) subjected to combined action of urethane and PEF, and another two groups subjected to urethane and microwave radiation of 460 MHz. Thus, the total number of groups in the experiment was 12, 6 of them containing males and 6 females.

During this experiment we observed the mice, weighted them and recorded the dates of death. Such outcomes were probably due to a certain toxicity of the exposures and characterised the contribution of random factors. So in the intact controls over 6 months of the chronic experiment we lost 1 mouse, female; in the groups of only microwave radiation - 3 males and 4 females; in the groups of urethane - 1 female; in the groups of combined influence of urethane and microwave radiation - 5 males and 4 females; in the ones with combined urethane and PEF - 1 male and, finally, in the groups of combined urethane, PEF and microwave radiation - 3 males and 3 females. On could conclude that the greatest loss of life was characteristic of the groups where the mice were subjected to the influence of microwave irradiation with non-thermal power.

After 6 months all the mice were slaughtered, their lungs were fixed and the number of tumours with a diameter greater than 0.2 mm on their surface was counted with the help of a binocular magnifying glass. The results of the experiment are given in following table:

As can be seen, the microwave radiation exposure results in a very weak, statistically insignificant carcinogenic effect, as the formation of tumours in the

lungs of the mice was observed only in 2 out of 23 mice, while in the control group there was 1 tumour among 29 mice.

NN	Groups	Average number of lung tumours, M+/-m			Frequency of tumours
		Male	female	all mice	
1-2	Intact control	0	<0,1	<0,1	3,4
3-4	Urethane	12,7+/-2,3	13,5+/-1,6	13,1+/-1,2	100
5-6	Microwave (MW)	0,3+/-0,1	0,3+/-0,1	0,3+/-0,1	8,7
7-8	Urethane+MW	25,0+/-1,0	25,2+/-1,7	25,1+/-1,4	100
9-10	Urethane+PEF	7,5+/-0,8	5,8+/-1,0	6,7+/-0,7	82,8
11-12	Urethane+ MW+PEF	10,4+/-1,2	9,2+/-1,4	9,9+/-0,9	87,5

However, the influence of microwave radiation of 460 MHz in this experiment nearly doubled the carcinogenic action of urethane according to the number of tumours formed in the lungs. Thus, the continuous microwave irradiation possesses a statistically significant and pronounced cocancerogenic effect. It is possible that such an increase in the frequency of lung tumour production in the groups with only microwave radiation is also a manifestation of cocancerogenic effect to the endogenous factors in the mice of this line. As likely as not, this cocancerogenic action of microwave radiation with non-thermal power involves not only the urethane effect, but also that of many other carcinogens, including those essential for human habitat. In this case, the main danger of microwave radiation in today's world will not be its own carcinogenic action, but its cocancerogenic effect. This calls for the search of new methods of protection against carcinogenic and cocancerogenic effects of electromagnetic radiation.

It was exactly in the search of new approaches to the solution of this problem that the present work studied the effects of PEF treatment, what we earlier (5) indicated by the term 'SPEF-therapy' (stimulation by pulsing electrical field with certain parameters). As can be seen from the results of the present chronic experiment, SPEF-therapy ensured a nearly two-time reduction of the average number of urethane-induced lung tumours in the mice and besides, in 5 out of 29 mice no production of pulmonary tumours was observed. SPEF-therapy proved to be effective also in relation to the cocancerogenic effect of microwave radiation. The average number of lung tumours formed by the combined influence of urethane and microwave radiation was reduced over 2,5 times, and besides, in 3

out of 24 mice of this group no production of pulmonary tumours was observed. The mechanism of anti-carcinogenic and anti-cocancerogenic actions of PEF remains unclear. One can advance a hypothesis that an important role in these processes is played by the (discovered by us) (7) ability of PEF to increase the production of nitric oxide in tissues, which can promote a reduction of the level of «oxidative stress» and reinforce the activity of repair enzymes in «target» cells and tissues.

Thus, the results of our experiments are indicative of the need to take into account not only the danger of carcinogenic but also of cocancerogenic action of microwave radiation with non-thermal power. Along with this, it was for the first time that a new way of weakening of the carcinogenic and cocancerogenic effects of different agents was discovered based on the conducting a treatment course of a new type of short physiotherapeutic procedures.

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CLINICAL MONITORING IN AREAS OF EXPOSURE TO RADIO FREQUENCY ELECTROMAGNETIC FIELDS

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The interpretation of changes in the workers' health conditions arising under the influence of electromagnetic radiation of radio frequencies is exceptionally complicated due a number of reasons, the main of which are as follows: the polymorphism of clinical manifestation with no prominent specific characteristics, with not many, or rather very few, observations with a marked verified picture of the disease, and imprecise, in some cases, hygienic characteristics of labour conditions. So it comes as no surprise that there is no common opinion on the possibility of interpretation of the clinical manifestations caused by the action of electromagnetic radiation as a "radiowave disease".

The present report contains a description of 11 clinical observations of the disease, caused by electromagnetic radiation. Four observations are concerned with occupational exposure to electromagnetic radiation in 1960-1970. Thus, in one observation a powerful general overexposure took place. It was so strong that it was followed by a brief loss of consciousness and neurological disorders in the form of ataxia. Nevertheless, the victim continued in his job for another 2 years, being exposed to 100 $\mu W/cm^2$ nearly 60% of his working time.

The second patient had been working for 7 years under the field intensity of 4 mW/ cm (4000 $\mu W/cm^2$), his total exposure period being 35-40% of his working time.

The third patient had been working for 13 years in enclosed premises, where 4 sources with an output power of 5-7 kW in the pulse mode were located.

The fourth (female) patient had been working for 10 years at an anti-hail station, where her daily exposure to 100-200 $\mu W/cm^2$ was more than 4 hours.

The patients were under observation of a medical institution and were frequently hospitalised (Scientific-Research Institute of Labour and Occupational Diseases) during 10-20 years. Thus, we had a unique opportunity to monitor the beginning and duration of the disease with known characteristics of labour conditions during such a long period of time.

The common feature for all subjects was the affection of the central nervous system, cardio-vascular system and blood system.

The affection of the central nervous system was considered as asteno-vegetative syndrome, hypotalamic disorders in the form of diencephalic syndrome. The data of electro-encefalographic examination showed diffuse changes of bioelectric activity of cerebral cortex with indications of irritation of the limbicoreticular complex. But the decisive factor in the classification of hypotalamic disorders was the clinical picture typical for the diencephalic syndrome.

The affection of the cardio-vascular system was indicated in manifested by neuro-circulation dystonia of the hypertonic type; a quickly disappearing hypotonic type was detected only in one observation and was later transformed into hypertension. All the subjects' ECGs showed changes which were regarded as myocardiodystrophy at the initial stage of disease with subsequent rapidly progressing coronary insufficiency, verified in one case by a large centre of myocardial infarction at the age of 40, in another case by paroxysmal glimmering arrhytmia at the age of 45 with subsequent myocardial infarction, and in the third case - IHD of a high functional class developed at the age of 39. In this connection one could doubt the interpretation of the ECG data as indication of myocardiodystrophy. In our observations a real IHD of a high functional class develops very quickly (within 3-4 years), and the changes in the arterial tension, interpreted as indication of nerve-circulation dystonia, are transformed into an authentic hypertonic disease.

Typically one observes a very rapid progress in the disturbance of lipid exchange. Thus, in one observation the cholesterol level within 3 years increased from 4.68 mmol/l to 8.32 mmol/l, in another observation - within 4 years from 3.9 mmol/l to 8.84 mmol/l, and in the third case - from 5.2 mmol/l to 8.32 mmol/l. Thus, within 3-4 years of observation the cholesterol level nearly doubled.

So, according to the data, radiowave radiation in large doses is a powerful risk factor for the development of atherosclerosis and early ageing. The affection of the blood system was manifested by leukopoenia which was found in all the subjects. In one case the changes in the leukocyte and, to a lesser degree, thrombocyte sprout were markedly progressing (Table 1).

In other studies the quantity of leukocytes in the peripheral blood varied from 2.7X10/l to 4.2 X10/l. But there were periods during more than 20 years of

dynamic observations with normal, or even tending to increase, content of leukocytes in the peripheral blood.

Table 1
Dynamics of leukocyte and thrombocyte content

Formal blood elements	Time lag between exposure and changes					
	Immediately after powerful micro wave radiation	After 3 years	After 6 years	After 8 years	After 22 years	After 23 years
Leukocyte, 10/l	4.8	3.6	3.4	2.5	2.4	2.1
Trombocyte, 10/l	-	150	-	-	156	-

Long-term observations allow us to assert that cytopoenia is one of the typical manifestations of the influence of radiofrequency electro-magnetic fields. But it is necessary to stress that, due to the phase character of the process, one may fail to detect cytopoenia.

Analysing the above observations, made over many years, as a whole and from the clinical positions, it is necessary to point out the wave-like course of that disease, with typical changes from improvements to acute conditions. But the main feature of the course of the disease is the progressive deterioration of health, increasing changes in the cardio-vascular system, progressing hypertension cardiac incompetence, related, though not only or to any great extent, to the age factor (since all the main events occurred within 3-4 years) but also to the laws (which remain yet unclear) of the progress of the main disease.

The changes described above are typical of all the victims. But a thorough individual analysis revealed some vital differences.

Thus, in the patient with marked changes in the blood system were comparatively few manifested lesions of the central nervous system in the form of the asteno-vegetative syndrome. In another observation, in the presence of grave diencephalic disorders there were no such marked changes in the blood system. In the third observation, the first place among the symptoms of grave asthenisation and cardiac pathology with comparatively insignificant changes of the blood.

It was the described circumstances, that, from our point of view, gave rise to doubts in the competency of the diagnosis "radiowave disease" as an independent nosologic form.

Its recognition as a new kind of disease finds no support for lack of a typical constant combination of symptoms, in other words, of specific manifestations.

Actually, in the mentioned observations no full combination of symptoms and syndromes in their determined correlation (constellation) is registered.

According to a commonly accepted interpretation, three main syndromes are singled out as regards the influence of electro-magnetic fields of radio frequencies: asthenic, asteno-vegetative and hypotalamic.

It is considered that these syndromes, in general, correspond to 3 stages of disease: initial, moderately marked and marked. We consider (as a hypothesis) that this is not a question of disease stages, but one of variants of clinical progress: mainly with the affection of the CNS, CVS and blood system. But in each variant the changes from other systems, as a rule, can be observed, but their prominence and proportional contribution to the clinics of the disease may be different.

In a thorough analysis of the above mentioned observations it was established that the clinical variants are determined by a number of circumstances and, in particular, by the character of radiation (the geometry of radiation, position of axes of the body with regard to the magnetic and electrical components of electromgnetic radiation and other characteristics).

An analysis of the above observations has shown that it was mainly haematological variant of the disease that was registered upon exposure to powerful total radiation, and the hypotalamic variant – upon exposure to local radiation (head, arms) was observed.

But due to the fact that geometry of radiation cannot always be defined, and the number of our observations was small, further observations are needed as well as further development of materials from this viewpoint, including experiments, though in this case there will be difficulties, connected with the methodology of estimation of the degree and character of responses from the functionally ambiguous parts of the body.

There are publications on the occupational exposure to electro magnetic radio frequencies of low intensity. Observed was the impact on the cardio-vascular

system, blood system up to the development of leukaemia. There are many publications devoted, according to the terminology used by non-Russian authors, to the changes in the behavioural reaction, i.e. in the central nervous system. It is no secret, that electromagnetic radiation can be used as a weapon too.

But there are only a few single publications on the development of clinically marked forms of the disease. And this is something qualitatively different, and on the whole, from the clinical positions, this factor has been studied surprisingly little.

In a WHO Summary, dedicated to electromagnetic radiation influence on humans, there are only 2 observations of American authors on the development of acute affection under the influence of electromagnetic radiation. Meanwhile, the present time is characterised by a combination of influence of different physical and chemical agents on human body, and among them, in particular, there is a new set of contaminators, the so-called "electromagnetic smog", that is an aggregation of electromagnetic fields, radiations and other manifestations of sophisticated electronic devices at work. It is quite clear that an uncontrolled increase of electromagnetic radiation can be an extremely powerful ecological factor, which is capable of influencing the health of the population.

The most vital contribution to microwave pollution is made by SHF apparatus, which are used for industrial and military purposes.

In this connection a study was made of the health status of those living in the vicinity of radar stations (within 600m) and affected by electromagnetic radiation with the density of the energy stream exceeding MPLs up to 20 times. A field team conducted a comprehensive medical examination of 30 persons aged 20-55 (male and female). Simultaneously a control group (28 persons) of similar composition in terms of age, sex, profession, social status and living conditions living at a distance of 4-5 km from the radars was examined.

The programme of research was conducted according to a 2-stage plan of medico-ecological monitoring developed by us (Table 2); polyclinic medical examination of the subjects of both groups was organised by a team of specialists including a GP and a neuropathologist.

Investigations were made of the peripheral blood, coagulation system, function of the thyroid gland, immune status of first the level, and all the medical documentation was also studied.

Table 2 Diagram of 2-stage medico-ecological monitoring

STAGE I TASK: Identification of the risk group
GENERAL PLAN: 1)Comprehensive medical examination
2)Estimation of hygienic living conditions

OBJECTIVES:		METHODS
MAIN	ADDITIONAL	
I. Syndrome of vegetative disorders	Elimination of pathology capable of causing a clinical picture similar to effects of SHF EMF action	1. Examination by neuropathologist, therapeutist
		2. Questionnaires
		3. Vegetative tests CI : (OKP)
		4. ECG
II. Syndrome of thrombocytopoenia, coagulopathy		1. Blood test + thrombocyte
		2. Period of coagulation
		3. Duration of bleeding
		4. Prothrombin
		5. Fibrinogen
III. Syndrome of reduced T 3, T 4.		1. Radioimmunoanalysis of blood serum (T3 and T4)
IV. Syndrome of secondary Immunodeficiency		1.Questionaire
		2.Determination of R-albumins Ig M,G,Ig A, C3 fraction of complement

STAGE II TASK: "Clarification of the character of the changes revealed and their connection with the effects of SHF radiation"

OBJECTIVES:		METHODS
MAIN	ADDITIONAL	
I.. Peculiarities of the syndrome of vegetative disorders	Differential diagnosis	1. Examination by neuropathologist, therapeutist, endocrinologist, haematologist, etc.
		2. Estimation of vegetal tonus (CERDO Index)
		3. Estimation of inter-system relationships (HILDEBRANT Coefficient)
		4. Estimation of biorhythm thermoregulation
		5. EEG and ECG

II. Peculiarities of syndromes of thrombocytopoenia and coagulopathy		1. Blood test + thrombocytes 2. Period of coagulation, kaolin time, factors VII,VIII, prothrombin index, fibrinogen, thrombin time, fibrinolytic activity of whole blood, tolerance to heparin, antithrombin III, VILLEBRANT factor, etc.
III. Syndrome of reduced T3 and T4		1. Radioimmuneanalysis of blood serum (determination of T3 and T4)
IV. Peculiarities of the syndrome of secondary immunodeficiency		1. Estimation of conditions of specific protective systems (immunogramme)

Table 3.
Frequency of combination of indicators according to individual analysis data

INDEXES	I GROUP n=30		II GROUP n=28	
	Absolute	relative	absolute	relative
Syndrome of vegetal disorders	24	o.80	10	0.36
SVD+ thrombocytopoenia	10	0.33	1	0.036
SVD+thrombocyto poenia+leukaemia	4	0.13	-	-
SVD+thrombocyto-poenia+indication of coagulopathy	10	0.33	-	-
SVD+blood changes + hyperplasia of thyroid gland	5	0.16	-	-

* reliable difference between groups ($P< 0.01$)

As a result of these observations of the affected subjects it was established that, in comparison to the controls, there was prevalence of the functional disorders of CNS in the form of the asteno-vegetal syndrome (63% and 22% correspondingly), hypotonia (13.3 % and 3.6%)

Changes of the peripheral blood were observed: reduction of the number of thrombocytes by 42.8 % and 5.3 % respectively in the main and the control groups, and leukocytes by 17.8 % and 3.5 %, longer bleedings (by 37.9 %, only in the main group).

Immunological examination showed changes in the indicators of humoral immunity expressed as a tendency to hyperglobulinemia M and G and hypoglobulinemia A, with changes in the T- and B – immune systems which reflected on the structure of infectious disease incidence.

Thus, the number of acute respiratory viral infections (more than 3-4 times a year) observed in the main group was almost twice as high (54% and 29.6 % respectively). In their totality the observed changes can be qualified as secondary immunodeficiency condition which requires bioregulating therapy.

To find out the frequency of a combination of these indications, individual analysis was performed (Table 3). The most significant, in terms of incidence in the main group, was the asteno-vegetal syndrome, and therefore this indicator was considered the principal one for analysis. It was also discovered that 14 subjects (46.6 %) showed a combination of functional disorders of CNS, cytopoenia and hyperplasia of the thyroid gland. It was those subjects who were directed to the clinic for an in-depth examination. Among the 7 subjects examined, "radiowave disease" was diagnosed in 6.

Thus, the problem of electro-magnetic pollution of the environment has been transformed from one of professional pathology into a medico-ecological one.

Conclusions

1. Interpretation of changes in the health status of those exposed to a chronic influence of SHF electro-magnetic radiation presents certain difficulties. This is first of all due to the polymorphism of clinical manifestations, absence of specific symptoms, phase and wave-like character of the course of disease, imprecision of the hygienic characteristics.

2. In those who live in the conditions of exposure to electro-magnetic radiation, created by the radar stations which exceed MPLs, functional disorders develop in the CNS and blood system; those are manifested in the form of such clinical syndromes as the syndrome of vegetal dystonia (asteno-vegetal syndrome, thrombocytopoenia, reduction of certain

indications of the coagulation system; change of the functional status of the thyroid gland.

3. The diagnosed clinical syndromes in the patients exposed to EM radiation may be regarded as syndromes of a disease related to chronic UHF action which exceeds MPLs. Thus, it is the first time that a chronic UHF exposure-related disease has been diagnosed among general population not occupationally connected with EM appliances. That has transformed the problem of electro-magnetic pollution of the environment from one of professional pathology into a medico-ecological one.

4. The application of our 2-stage monitoring system has demonstrated the efficacy of our methods approach aimed at an early detection of EMI effects on human health and made it possible to diagnose the EMI-related disease.

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CHRONIC ELECTROMAGNETIC FIELDS EXPOSURE EFFECTS ON THE HAEMATOPOIETIC SYSTEM

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The problem of the chronic influence of electromagnetic fields (EMF) on the haematogenic system has been repeatedly raised in Russian and foreign literature in the course of the history of electromagnetic biology. On the one hand, these are the results of clinico-epidemiological observations of the personnel, working under exposure to factors of electromagnetic nature factors, on the other — the experimental data obtained by modelling of occupational irradiation of bio-objects. Without any detailed critical analysis of the existing literary reviews, we may state that the chronic influence of EMF can provoke different kinds of changes in the blood system and these changes are characterised by instability. Nevertheless, the majority of the authors point to the unreliable character of the changes and the non-specifity of the manifestations peculiar to many unfavourable occupational factors. But there are no doubts that at the levels of exposure greatly exceeding MPLs influence changes in different blood systems will be found.

Recently a new electromagnetic factor, characterised by impulses of ultra-short duration (IUSD) of high energy of wide-band range of frequencies, has emerged in a number of industries. In some countries, including our country, there are no normative documents regulating this factor in industrial conditions, and this provokes justified fears on the part of the personnel and doctors — occupational pathologists, The more so, as the subjective symptomatology of the personnel occupationally exposed to IUSD EMF is quite varied and requires an additional objective assessment.

Methods Basis for the Conduct of Experiments

One of the verification methods for the hypothesis concerning the unfavourable action of any occupational factor is to conduct an experimental investigation on animals. Considering the problem of biological action under simulation of occupational exposure, it is impossible to ignore the problems, related to the adequacy of this simulation and subsequent extrapolation of the obtained results from bio-objects to humans. In an experiment the conditions of professional activity must also be modelled as closely as possible, beginning from the parameters of principal expose factors to temporary conditions, related to the age of bio-objects and their life expectancy.

The experiments have been conducted on white male rats of no particular breed on the basis of periodisation of postnatal growth of male rats and male humans (Machinko, Nikitin, 1975), and also the correlation analysis of human age (A_h, yrs) to rat age (A_r, yrs) the next mathematical model of re-computation.

$$A_r=A_m(10^{1,738lgA_h-2,819}).$$

Considering that the occupational exposure age is 22 to 45, the corresponding rat ages for the experimental model were from 4 to 14 months.

Therefore the whole period of the chronic experiment on rats lasted 10 months.

The exposure levels were selected in such a way that the densities of occupationally induced currents (DIC) in the human body were equivalent to the levels of currents in the body of the experimental animals. On the basis of literature data (Kaune W.T., Forsythe W.C., 1980), these parameters for rats are 12,5 times higher, than for humans. In our experiment we created the levels of E-field intensity of such value, that the averaged levels of DIC were 3.7; 7.0; 8.0 and 27.0 A/m^2. This scale gives an adequate possibility of conducting both interpolation and extrapolation for other levels of DIC. In addition, provision was made for a biological control group (BC). Due to the statistical uncertainty of periodicity of human occupational exposure, the animal experiment models provided for the following number of pulses (their duration was 15—40 ns) at each level of exposure: 50, 100 and 500 per week, irrespective of the distribution of these pulses on separate days.

Methods of Investigation

For assessing the haematological status of the experimental animals their haemopoietic status was examined: peripheral blood and medullary haemopoiesis. The peripheral blood was drawn from the caudal vein, while the bone marrow – from the femur of decapitated animals. The smears of peripheral blood and bone marrow were stained according to Pappenheim-method. In the peripheral blood we determined: number of leukocytes, erythrocytes, reticulocytes, thrombocytes, haemoglobin content, and also the leukogram. To determine the total amount of myelokaryocytes of the femur the bone marrow was washed away with a syringe with 5 ml of «199»-medium with the following repeated homogenising washing via a needle. Cellular suspension was taken with the help of an erythrocyte mixer. The calculation was conducted in the Goryaev-chamber. On the basis of the peripheral blood analysis an estimation of two generalised indices was made:

integral coefficient of blood impairment (ICDI) and entropy of leukocytic blood count (EHBC) (Tickochuk V.S., et al., 1991). The biological material samples were taken on the 5^{th}, 7^{th} and 10^{th} month of the experiment.

For a mathematical analysis of the experimental, the comparison of dependent and independent samples with the help of Student-t-criterion and linear regressive analysis was made (Huble E.V., 1978).

Results of the Investigations and Discussion

After 5 months, irrespective of the parameters of USD EMF pulses we observed a trend towards white cells quantity increase compared with the data of BC. This finding is basically related to the augmentation tendency in absolute and relative lymphocyte quantity. In the red blood cells there was noted a proclivity to decrease of erythrocytes and haemoglobin levels with maximal deviations, typical for the most intense exposure modes. This, in general, also involves reticulocytes: in comparison with BC, a reliable increase in their number was revealed in the most intense exposure modes (100 and 500 pulses at DIC 27.0 A/m2). No specific patterns of change in the number of platelets could be observed.

The data of the bone marrow investigation in the same period suggest that, irrespective of the parameters of the acting factor, there was a trend to a reduction in the total count of myelokaryocytes in relation to BC. In some experimental groups a reliable decrease in their number was revealed. An analysis of the cytological composition of bone marrow revealed an upward trend in the percentage of myeloid stem cells with a simultaneous increase of early generation cells in the proliferating pool (myeloblasts). Somewhat different was the character of erythropoetic stem shifts: there was a trend to augmentation of premature cells of haemoglobin-lacking elements (proerythroblasts), which did not tell on the total count of the erythroid stem cells, and their dynamics was unspecific. Also noted was an upward trend in the percentage of monocytes and lymphocytes in the bone marrow, irrespective of the intensity of the acting factor parameters.

Therefore, five months from the exposure date, one noted the signs of leukopoiesis activation, manifested by an increase of the total number of bone marrow myelocytic cells as well as leukocytes, lymphocytes and platelets in the peripheral blood. Activation in erythropoiesis was manifested by augmentation of the reticulocyte count. A simultaneous reduction trend in the erythrocyte and haemoglobin levels indicated a strain on the body's compensatory resources.

After 7 months, only the peripheral blood indices were analysed. It was established that the directivity of the changes had been preserved, though they were much less marked, than after 5 months. In that period there was an upward trend in the number of thrombocytes, irrespective of the acting factor parameters. All that suggested the preservation of some indices of activation due to the adaptational-compensatory mechanisms.

After 10 months, the number of leukocytes uncertainly fluctuated due to neutrophil and lymphoid cells. In the red blood (erythrocytes, haemoglobin) and platelets no reliable changes were detected in comparison with BC. There was a noted trend to a decline in the reticulocyte count, however, under exposure to EMF with DIC 27.0 A/m2 and 500 pulses, a reliable increase was observed as compared to BC.

The investigation of the bone marrow haemopoiesis in this period revealed a reliable decrease in the total number of myelokaryocytes, which was inversely proportional to DIC and the number of pulses. An analysis of the bone marrow cell content indicated a tendency to a reduction in myelocytic elements due to the reduction in the number of mature neutrophils, which is merely inversely proportional to the quantity of acting pulses. The dynamics of the share of young formed cells (myeloblasts and promyelocytes) showed their higher level as compared to BC, which was proportionally only to DIC. The character of shifts in the erythropoiesis was different from the alterations seen in leukopoiesis. There was an increase in the total count of erythroid in proportion to the number of acting pulses. The premature generation cells' count (proerythroblasts) reliably increased in proportion to the number of the acting pulses. Simultaneously one observed an increase in the basophilic normoblasts in proportion to DIC and the number of pulses.

The regression analysis conducted allowed to determine the mathematical models of the dynamics of changes in the cellular forms of the bone marrow. The reliable models ($p<0.05$) and their mathematical expression are presented in figures 1 to 4.

Thus, 10 months after the exposure, we found obvious signs of myeloid stem suppression, which were manifested by a drop in the total count of myeloid cells primarily due to a reduction in mature neutrophils of the bone marrow, though such changes did not tell on the peripheral blood indices. In the erythroblastic stem there was a marked augmentation of proliferating activity, characterised by a simultaneous increase in the total number of erythroid cells, proerythroblasts basophilic normoblasts.

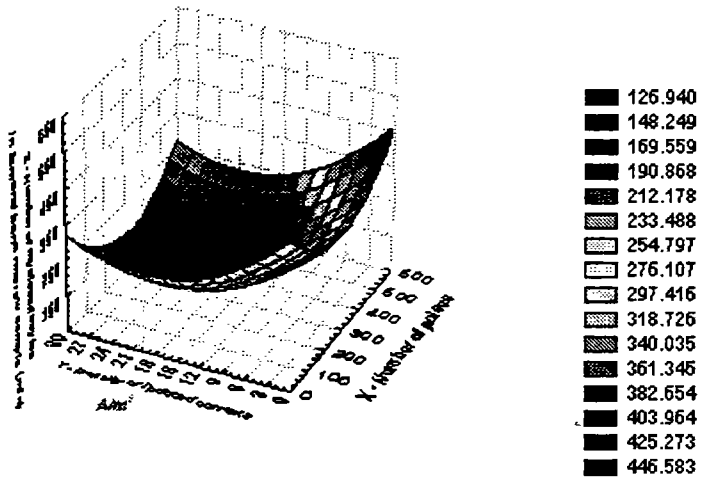

Fig.1. Dynamics of yelokariocytes total content change. Mathematical model: $Z=467.89-0.97X-20.45Y+0.002X^2+0.003XY+0.521Y^2$

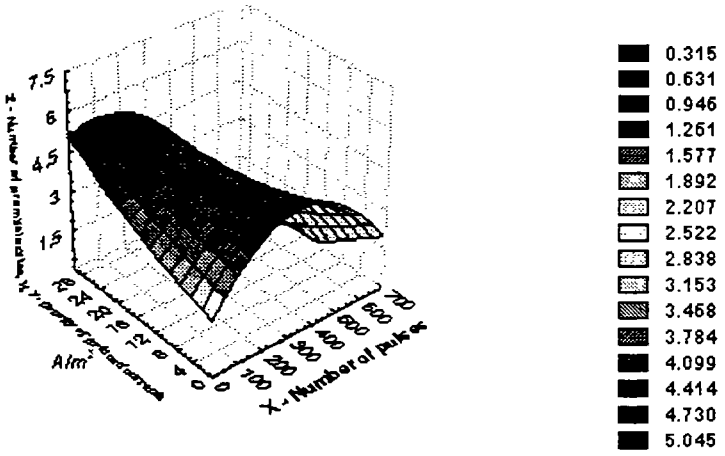

Fig.2. Dynamics of bone marrow early generation cells number change (promyelocytes), %. Mathematical model: $Z=1.12+0.014X+0.057Y+0.001Y^2$

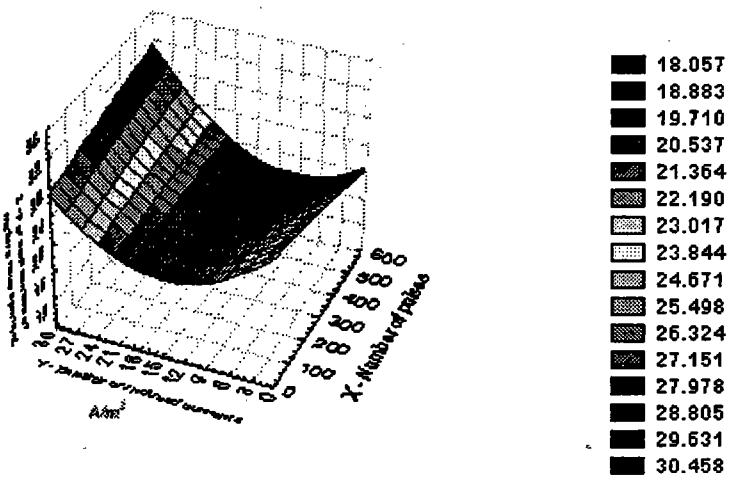

Fig.3. Dynamics of mature neutrophils content change, %. Mathematical model: $Z=19.174-0.009X-1.027Y+6X^2+0.034Y^2$

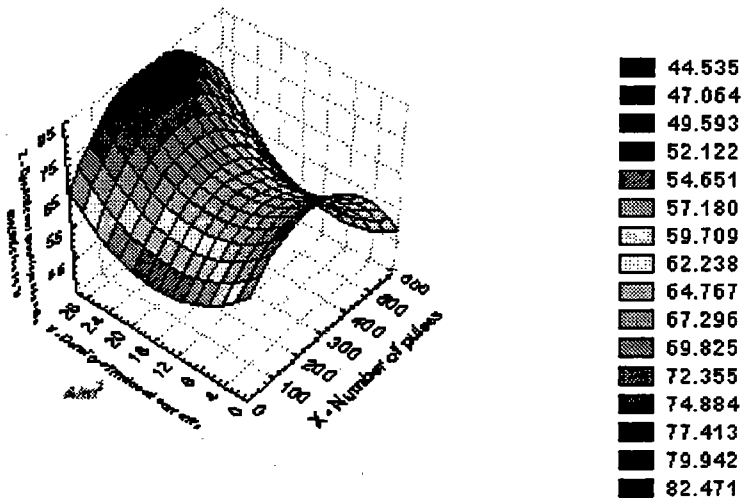

Fig.4. Dynamics of granulopoietic cells content change, %. Mathematical model: $Z=66.5+0.1X-1.882Y+0.001XY+0.062Y^2$

As a result of the experimental investigations performed on chronic effects of pulses of wide frequency band of USD EMF on biological objects, we established certain shifts in the leuko- and erythropoiesis. These alterations were phased in character and were non-homogenous. In general, they may be described as a manifestation of compensatory capabilities of haemopoiesis, with a more stressed and accentuated compensation of its erythroblast stem. The degree of expression of the haemopoietic general reaction to the given impact entitles us to state that erythroid haemopoiesis is more sensible to the EMF factor.

MNESTIC DISORDERS CAUSED BY UHF-FIELDS AND THEIR PHARMACOLOGICAL CORRECTION

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It is known that the effect of the UHF-field can cause disorders of memory and learning in humans and animals [18, 19, 20]. Thus it was established that pulse microwave radiation with high peak power causes the reduction of memory in rats [24, 28]. But in the available literature there are only a few works dealing with the pharmacological correction of the mnestic disorders caused by UHF-fields. Lai et al. [27] have shown that after a 45-minute exposure to pulse microwave radiation at 2450 MHz frequency (pulse duration - 2 μs, 500 pulses per second, density of power flow - (DPF) - 1 mW/cm^2, 0,6 W/kg) rats show retardation of learning in a maze with food stimulation, which points to the disturbance of the space memory. These disorders were blocked with a systemic infusion of reversible cholinesterase inhibitor physostigmine and with specific opiate antagonist naltrexone. At the same time the inhibitor of the peripheral opioid receptors naloxone metyiodide did not have positive effects. Therefore, space memory disorders after UHF-influence are connected with alterations of the cholinergic and opioid systems of the CNS.

Our experiments have shown that a 1-hour exposure of rats to a low intensity UHF-field (frequency 2375 MHz, DPF 1 mW/cm^2) causes amnesia of the conditioned reaction of the passive avoidance (CRPA), whose expression decreases within 24 hours. This effect is, in all probability, generally caused by non-thermal action of the UHF-field on the body, because the threshold of the integral thermal effect in the UHF range is situated in the DPF-area of 10-11 mW/cm^2 [3, 6, 23]; e.g. at a low intensity of radiation (no more than 10 mW/cm^2) the total heating of irradiated objects usually does not exceed 0,1°C [15], while the DPF threshold of the increase in rectal temperature in rats at 2450 MHz is 20 mW/cm^2 after 1 hour or 10 mW/cm^2 after 2 and 4 hours.

It was found that amnesia developed only in the case where a UHF-field acted immediately after the learning session. The UHF-field action at the stages of acquisition of information, transition of short-term memory into long-term, and extraction of the memory traces did not show any statistically reliable changes of the processes of learning and memory. Therefore, the most UHF-sensitive stages are the initial stages of the process of the memory trace consolidation. In order to access the specificity of the UHF-field effect on the mnestic functions it was necessary to exclude the possibility of its action on some behavioural reactions of

animals, first of all on the motor activity and on the perception of electrotome stimulator, which is used as an unconditional support in the CRPA-test, as such behavioural changes could imitate the amnestic effect [13, 14, 16].

It was found that UHF influence does not change the indices of rat behaviour in the «open field» (including motor and vertical activity), or affect their pain sensitivity (in particular, according to the «vocalisation test»). At the same time UHF-field can cause a pronounced retrograde amnesia in rats (CRPA-test). Other investigators [12, 11] did not find changes in the behavioural activity of rats («open field test» - the original maze method with the registration of the motor activity) either after a single continuous 7-hour action of microwave radiation (DPF 0,1 and 1,0 mW/cm^2, frequency 2375 or 2450 MHz). Therefore, one can conclude that the amnestic effect of UHF-field we found is specific.

The comparison of the basic mechanisms of retrograde amnesia caused by UHF-field and by the traditional amnestic agent - the electro-convulsion shock (ECS) has shown important differences between both. At the present time there are well-grounded proofs that ECS acts mainly on the process of reproduction of the engramme of memory, inhibiting its realisation i.e. accelerating the process of forgetting the memory trace [21]. In particular, the application of ECS 2 hours after the learning the rats (CRPA) caused the amnesia of the acquired habit in 30% of the animals [4]. On the contrary, in our experiments the UHF-field application 1 hour after the learning sessions did not cause the amnestic effect in the rats (CRPA-test).

We performed a neuropharmacological analysis of the UHF-caused amnesia that showed that different neurochemical systems (substances with selective action on definite neuromediator brain systems were used) take part in its realisation.

It follows from table 1 that the amnestic effect was reliably diminished by the following substances: naloxone - universal blocking agent of the opioid receptors, ICI 174,864 - selective blocking agent of opioid delta-receptors, glutamate diethylester (GDE) - antagonist of the non-NMDA-type receptors of excitation aminoacids (EAA), specific non-competitive antagonists of NMDA-receptor complex - MK-801 and ketamine, blocking agent of chlor-ionophore part of GABA - benzodiazepine receptor complex - picrotoxin, specific antagonist of GABA-receptors - bicucullin, dopa-mimetic - d-amphetamine and physostigmine - the reversible inhibitor of cholinesterase with central activity. The amnestic effect was not influenced by: alpha-adrenoblocking agent phenoxibenzamine, beta-adrenoblocking agent propranolol and quarternary analogue of naloxone - methylnaloxone, which mainly blocks peripheral opioid receptors. The inhibitor of

serotonine synthesis para-chlorphenilalanine (PCPA) slightly diminished the expression of UHF-amnesia, but the blocking agent of dopamine receptors haloperidol intensified amnesia, but this was not reliable. Therefore it could be suggested that in the genesis of the UHF amnesia the most important role is played by endogenous opioids, acetylcholine, catecholamines (dopamine for the most part), EAA and GABA, the least role - by serotonine. The effect of endogenous opioids is realised through different types of opioid receptors of the CNS (at least mu- and delta-receptors), EAA - through kainate, AMPA/quisqualate and NMDA-receptors, GABA - through GABA-benzodiazepine receptor complex.

It was established in our laboratory [8, 9] that under the influence of a UHF-field the quantity of m-cholinereceptors in the brain cortex is growing without change of their affinity to the ligand - 3H-chinuclidinil benzylate; the number of benzodiazepine receptor in rat cerebellum diminishes; the GABA receptor capacity in sinaptic membranes of the neocortex and cerebellum is diminished (the reduction of the maximal concentration of specific binding sites of 14C-GABA is 31% and 35% to the control respectively), the effectiveness of conjugation of GABA-benzodiazepine receptor system in cortex is also diminished, furthermore in the hemispheres cortex the ability of acetylcholine to raise up the intra-sinapse concentration of free calcium ions is diminished.

Our results are corroborated by literature data. Thus, other authors have found that a 5-60 minutes action of the microwaves with the modulation frequency of 16 Hz (800 or 880 MHz, DPF 1-3 mW/cm^2) results in diminishing of the specific binding of 3H-muscimol by sinaptic membranes of the rats' brain cortex (i.e. in diminishing of the GABA receptors), as well as in diminishing of the cholinesterase activity [1, 10]. It should be stressed that the 16 Hz UHF-field, modulated by the rectangle pulses, makes changes in Ca 2+ output from brain tissue [22]. Furthermore, according to V.F. Katkov et al. [7] investigations, the modulated UHF-field causes a marked effect on calcium-dependent processes, taking place with the participation of the calmoduline - the intracellular regulation protein, which selectively binds Ca 2+ ions and which is a universal intracellular mediator of the calcium action, being a cofactor in the various calcium-dependent processes [17]. Depending on the modulation mode, the UHF-field can raise the calmoduline levels in the sensomotor cortex and hyppocampus of the rats.

In recent years data were obtained that dopaminoergic systems of the brain could mediate in some degree the effect of UHF-field on human or animal CNS [2, 3]. In particular it was found that the activity of the tirosinehydroxilase - which is the limiting factor of the dopamine synthesis in the brain diminishes in rat hypothalamus after irradiation with low intensity UHF-field, and after 1 hour UHF-

application (DPF 8 mW/cm^2, supporting frequency 880 MHz, modulation frequency 16 Hz) the dopamine related behaviour of rats is suppressed (apomorphine - induced rotation) [3]. Low-energy microwave radiation (supporting frequency 2450 MHz, modulation frequency 500 Hz, DPF 1 mW/cm^2, duration 45 min) diminished the hypothermia at rats induced with d-amphetamine [25]. Therefore the importance of the dopaminoergic brain system in the genesis of UHF-amnesia we previously discovered does not contradict the literature data.

A detailed investigation of various types of opioid receptors of some brain structures of rats and of their role in the realisation of the central effect of the microwave radiation of low intensity (supporting frequency 2450 MHz, modulation frequency 500 Hz, DPF 1 mW/cm^2, duration 45 min) was performed by Lai et al. [26]. They found that in the realisation of the inhibition by UHF of the Na+ dependent high affinity capture of choline in hyppocampus (but not in the frontal cortex) partake μ-, delta- and kappa-receptors.

We have found that various nootropic preparations (aniracetam, oxyracetam, piracetam, acephen, nooglutil, mexidol, GVS-111, GABA, ACTH fragments and their analogues) could serve as a mean of pharmacological correction of the mnestic disorders caused with UHF-irradiation. The most active in this relation were pirrolidone derivates oxyracetam (100 mg/kg) and aniracetam (50 mg/kg), which completely prevented the development of the amnestic effect in rats during the whole time of observation (24 h). At the same time N-acetylglycinamide with the doses of 1 and 10 mg/kg - in which doses it possesses evident nootropic and antiamnestic properties in the electroshock model - did not show antiamnestic activity. Besides, in contrast to pyracetam and oxyracetam, it did not improve the dynamics of elaboration of CRPA under subchronic (4 days) UHF-application.

The antiamnestic effect of the above-mentioned drugs is, in all probability, based on those neurochemical mechanisms which play some role in the development of UHF-amnesia. Thus, for pirrolidone derivates (oxyracetam, piracetam and aniracetam) such neurochemical target are in particular the following neuromediator systems: EAA-ergic, opioid-ergic (for piracetam and oxyracetam) etc, for acephen - the cholinergic, dopaminergic etc. Besides it could not be excluded, that the above mentioned nootropes could realise their antiamnestic effect as well through influence on metabolic (energetic) processes of the brain, as through direct action on the membranes [5].

Table 1

The influence of substances on the amnestic effect caused in rats by UHF-field

Experiment conditions	The total number of rats	The number of rats which learned CRPA	The number of rats with retrograde amnesia) by CRPA test= after irradiation	
			0 h	After 1 hour
Isotonic solution of NaCl + sham irradiation(control 1)	30	28(93%)	5(17%)	6(20%)
Isotonic sol. of NaCl + UHF (control 2)	30	26(87%)	23(77%)	19(63%)
Naloxone + sham irrad.	10	9(90%)	1(10%)	1(10%)
Naloxone + UHF	20	17(85%)	8(40%) **	8(40%)
Methylnaloxone +sham irrad.	6	5(83%)	1(17%)	1(17%)
Methylnaloxone + UHF	7	6(86%)	5(71%)	5(71%)
ICI 174,864 + sham irrad.	10	8(80%)	2(20%)	2(20%)
ICI 174,864 + UHF	20	17(85%)	10(50%) *	10(50%)
Para-chlorphenilalanine(PCPA) + sham irrad.	10	9(90%)	2(20%)	2(20%)
PCPA + UHF	10	9(90%)	6(60%)	6(60%)
Glutamate diethylester(GDE) + sham irrad.	10	8(80%)	3(30%)	3(30%)
GDE + UHF	18	15(83%)	9(50%) *	9(50%)
MK-801 + sham irrad.	20	14(70%)	7(35%)	7(35%)
MK-801 + UHF	20	14(70%)	9(45%) *	9(45%)
Ketamine + sham irrad.	20	16(80%)	6(30%)	5(25%)
Ketamine+ UHF	20	15(75%)	10(50%) *	11(55%)
Picrotoxin + sham irrad.	10	9(90%)	2(20%)	2(20%)
Picrotoxin + UHF	20	16(80%)	10(50%) *	11(55%)
Bicucullin + sham irrad.	10	9(90%)	1(10%)	2(20%)
Bicucullin + UHF	20	17(85%)	9(45%) *	9(45%)
Physostigmine + UHF	19	16(84%)	8(42%) *	8(42%)
Phenoxybenzamine+ sham irrad.	10	8(80%)	2(20%)	2(20%)
Phenoxybenzamine+ UHF	10	8(80%)	7(70%) o	7(70%) o
Propranolol + sham irrad.	10	8(80%)	2(20%)	3(30%)
Propranolol + UHF	10	8(80%)	6(60%) o	6(60%) o
Haloperidol + sham irrad.	18	15(83%)	9(50%) o	9(50%) o
Haloperidol + UHF	10	9(90%)	9(90%) ooo	9(90%) ooo
D-amphetamine + sham irrad.	10	8(80%)	1(10%)	1(10%)
D-amphetamine + UHF	20	17(85%)	9(45%) *o	9(45%) o

Note. One asterisk (or circle) - $p<0,05$; two - $p<0,01$; three - $p<0,001$ - reliability of difference in comparison with control 2 and control 1 (the exact Fischer's method).

It was found that the antagonist of non-NMDA-type receptors of the EAA diethylester of the glutamate considerably weakens the antiamnestic effect of the nooglutil, and the central m-cholinoblocking agent amisil near completely inhibits the analogous effect of semax. Thus, one can suppose that the antiamnestic activity

of the nooglutile is partially due to the activation of the non-NMDA-type receptors of the EAA, and as for semax it is due to the m-cholinergic mechanisms. GDE does not completely block the antiamnestic action of the nooglutil, so apparently in this effect also play some role other neuromediator systems, in particular choline- serotonine - and catecholamineergic. The monoaminoergic component of the protective mechanism of action of semax is also not to be excluded.

By means of a special series of experiments on cats with the use of microelectrodes and microinjections (microionophoretic injections) it was found that the mode of action of the investigated preparations on the highest integrative brain functions and the protection of the latter from the damaging influence of UHF-field is found to the high sensitivity to the nootropes of the neurones of the cortex: 58-84% of neurones of the 1-st somatosensor zone and 60-82% neurones of the 5-th field of the sinciput associative cortex (table 2).

It is notable that nooglutil causes principally the excitation effect on the spontaneous activity of the neurones of the fields of neocortex mentioned above, other nootropic agents cause mainly the inhibiting effect.

Table 2
Effect of the microionophoretic injections of the nootropes on the spontaneous activity of the neurones of the cortex

The zone of brain	Drugs	Total neurons	Effect		
			Exciting	Inhibiting	Absent
I Somatosen-soryzone	Nooglutil	19	13	3	3
	Semax	35	12	10	13
	AKTH(5-10)	31	9	9	13
	Mexidol	23	0	14	9
	GVS-111	26	5	14	7
	Piracetam	38	6	20	12
	Oxyracetam	31	4	18	9
The sinciput associative cortex (5-th field)	Nooglutil	17	12	2	3
	Mexidol	21	1	12	8
	GVS-111	25	4	13	8

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REACTION OF CENTRAL NERVOUS SYSTEM TO LOW-LEVEL AND SHORT-TERM MICROWAVE IRRADIATION

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In the present report a comprehensive description of the action of the central nervous system (CNS) to a short-term microwave irradiation with a power density (S) less than 500 μWcm^{-2} is given.

In experiments on rabbits we studied bioeffects of microwave EMF at the level of separate neurones, brain as a whole and the body. Various characteristics of microwaves (6 GHz or 1,5 GHz, modes: continuous, pulse, packet pulse, S 30 - 500 μWcm^{-2}, time of irradiation - 20 sec., 1 min, 5 min - singly or repeatedly) were used as well as various values of the initial physiological background.

The totality of the results obtained testifies, that the microwave with S < 500 μWcm^{-2} is a stimulus for CNS. Its biological importance can be various and is determined, not so much by the microwave parameters (within the investigated limits), but rather by the initial background conditions and temporary characteristics of the irradiation.

Thus, a 20 sec. microwave exposure (6 GHz, meander 60 Hz, S pulse 400 μWcm^{-2}) in the mode of conditional reflex development can become a conditional signal. In comparison with known adequate stimuli (light, sound), the conditional reflex to a microwave EMF developed reliably more slowly and was less strong (Table 1).

An analysis of the pulse activity of neurones has suggested the possibility of closure of the conditional connection in case of microwave EMF in one point: in at area of presentation of the unconditional reinforcement. This method (as one of the possible) was described by I.P. Pavlov (1937). The following data from our results testify to it.

- Direct action of microwaves on the brain tissue is possible, when it is mostly head that is exposed;
- There is a convergence of pulses of different modalities on one neurone, since in most cases the same neurone responded unidirectionally to three or

two stimuli (light, sound, microwave EMF). No neurones, responding only to microwaves, were detected (Figure 1)

- There is no reliable difference in neurone reactions to microwaves in various areas of the cerebral cortex (Table 2).

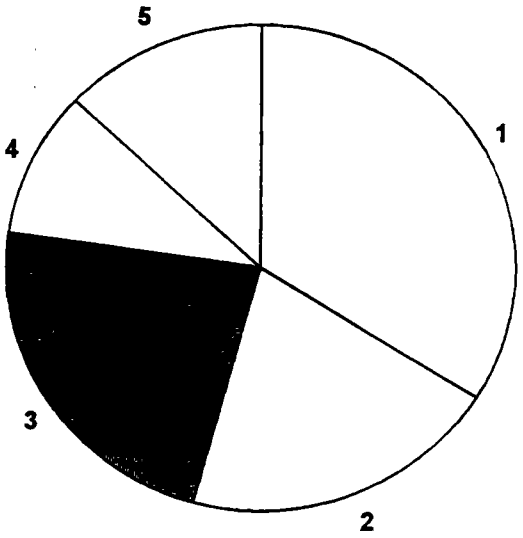
Table 1
Comparative characteristics of the development of conditional avoidance reflexes to different stimuli in rabbits

Conditional Signal	Occurrence	Strengthening	Maximum strength for 50 combinations	Mean period of delay of a response after strengthening
	(№№ combinations)		(%%)	(s)
Light flashes (50 Hz, 0,62 J) (n=5)	8±2,4	120,8±11,2	78,8±2,8	4,9±1,1
Sound clicks 50 Hz, 15 dB above the threshold of human audibility (n=5)	19,4±2,1	108±16	70±4,1	5,2±0,2
Microwave 6 GHz, meander, 50 Hz, $_{cp}$=200 μWcm^{-2} (n=5)	* 40,2±6,2	* 154±9,1	* 54,7±5,2	* 7,9±0,4
Constant magnetic field 1000 Oe (n=5)	* 41,8±2,7	* 248±4,8	* 48,4±3,4	* 8,5±0,12
Control (n=5)	82,2±38,9	No	5,5±1	-

Note: discontinuation of an unconditional reinforcement from the beginning of action of a conditional signal - 20s.
The unconditional reinforcement - subthreshold electric current, joint action - 2,5 s., *$p < 0.05$ concerning light and sound, n - quantity of rabbits.

It is possible to explain the difficulty of the development of reflexes to microwaves by special features of reaction of the brain to the given influence. The microwave with the various (above-stated) characteristics more often resulted in a reduction of frequency pulsing neurones. The dependence on the mode of irradiation was expressed in the quantitative ratio of inhibiting and stimulating neurones. Reactions to microwaves were realised with latent periods of 5 - 10 sec. The appropriate responses to known adequate stimuli (light, sound) differed: by a

smaller latent period, prevalence of reaction of activation in adequate area, by the ambiguity of display of reaction in various areas of the brain, smaller dependence on the initial background. The latter is an important characteristic of CNS reaction to the analysed low-level microwaves. An authentically lower background frequency was observed in the activated neurones, than the inhibited ones under the influence of microwaves (Figure 2).



From 70 neurones:

1. Reaction to light, sound and MICROWAVE (34 %);
2. Reaction to light and MICROWAVE (20 %);
3. Reaction to light (23 %);
4. Reaction to light and sound (13%)
5. Absence of reaction (10 %);

Fig. 1. Convergence of pulses of different modalities on the neurones of the visual area of the cortex of a rabbit.

The special features of CNS reaction to short-term low-level microwaves also found their reflection in the total bioelectrical activity of the brain (EEG). The reaction of the brain to a 5-minute exposure to microwaves in all the above-stated modes EEG was wholly determined by the initial background and more often was displayed immediately after, rather than during irradiation. It was realised with large latent periods (mode - 20 sec., range 5 sec. - 1 min) and consisted in an

increase of the number of fluctuations in alpha and beta ranges. The changes in EEG (unlike in the neurones) were not uniformly distributed among the areas (mainly in the parietal area on the right). However it was not accompanied by an authentic change of the correlation between EEG of the distant areas of the cortex. It is important to note, that with the all modes, considered by us, of a microwave (20sec., 1 min or 5 min) the irradiation did not result in authentic changes in the pneumogram, ECG or EMG, which were registered in parallel with the electrophysiological parameters of the brain. The above materials on EEG reactions point to the 5-minute microwave EMF as the subthreshold stimulus for CNS. The increase S in the interval 30-500 μWcm^{-2} did not result in an increase of the biological significance of microwaves. The dependence on S was not proportional, a tendency to the manifestation of so-called of power "windows" was observed (Figure 3).

The biological importance of low-level microwaves could have been strengthened by the change of the temporary character of the exposure or the initial background. 10 five-minute microwaves exposures with random intervals of 5 - 15 minutes could have resulted in a cumulation of the bioeffects. As a result, in an initially normal animal with implanted, so-called 'artefact-free' electrodes, one observed an adaptation reaction in the form of moderate activity. Thus, in the EEG spectrum one observed an increase of the theta range, and in the spontaneous motor activity - its strengthening. Absolutely the same microwave EMF, but against the background of functional deficiency of CNS, or in the presence of metal electrodes and wires, could result in a reaction of the body going beyond the limits of normal functioning (Figure 4).

In many respects similar results were obtained by us earlier in the study of CNS reaction to a constant magnetic field (S.N. Lukianova, thesis, 1970). The similarity of CNS reaction to various penetrating stimuli of magnetic and electromagnetic nature has repeatedly been mentioned by Yu.A. Cholodov (Monograph, 1966, 1975 etc.). The materials, presented in this report, corroborate and supplement these ideas.

Table 2

THE QUANTITATIVE CHARACTERISTIC OF REACTION OF CORTICAL NEURONS OF THE BRAIN OF A RABBIT PER 1 MIN. OF EXPOSURE TO VARIOUS PHYSICAL FACTORS

Physical factor	Percent of cases Reliable changes of frequency pulsing neurones			
	Visual region		Sensorimotor region	
	Activation	Braking	Activation	Braking
Microwave 1,2 GHz, Continuous mode, S=300 μWcm^{-2}	7,1 n =	31,5* 56	7,6 n =	37,4* 72
Microwave 1,2 GHz, Pulse mode, F=0,12 Hz, τ=16μs, Spuls= 300 μWcm^{-2}	10,0 n =	54,5* 90	14,5 n =	59,68* 124
Microwave 1,2 GHz, Pulse mode F=1000 Hz, τ=0,4ms, Spuls = 300 μWcm^{-2}	25 n =	29,7 105	27,6 n =	32,38 84
Microwave 1,2 GHz, packet-pulse mode , F=1000 Hz, Fpacket=0,12 Hz, τ=0,4 ms, Spuls = 300 μWcm^{-2}	23,23 n =	30,4 63	24,1 n =	31,0 76
Microwave 6 GHz, Meander 50 Hz, Spuls = 400 μWcm^{-2}	-	-	6,4 n =	49,25* 67
Constant magnetic field, 1000 Oe	23,4 n=	36,36 41	24,69 n=	30,86 40
Light, 50 Hz, 1 ms, 0,62 J	60,97 n =	25,47* 207	-	-
Sound, 50 Hz on 15 dB, Above the threshold of human audibility	16,4 n =	29,8 108	-	-
Control	10,9 n =	3,8 71	13,1 n =	8,2 62

$p < 0,05$ in relation to % of cases of activation.

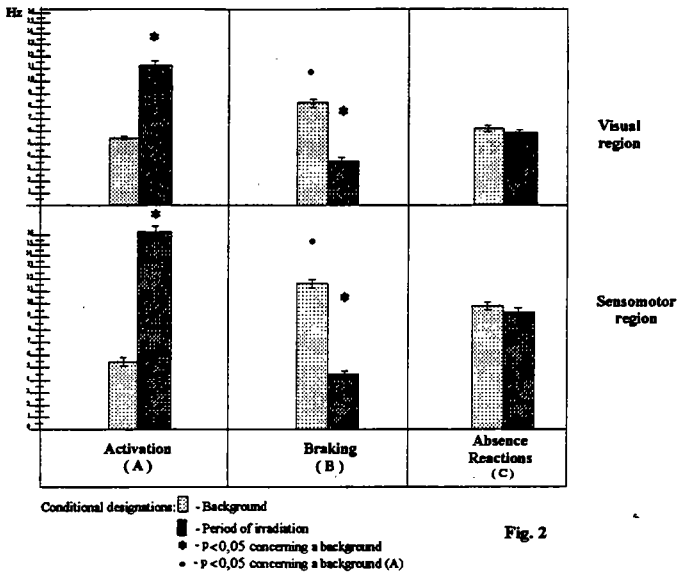


Fig. 2

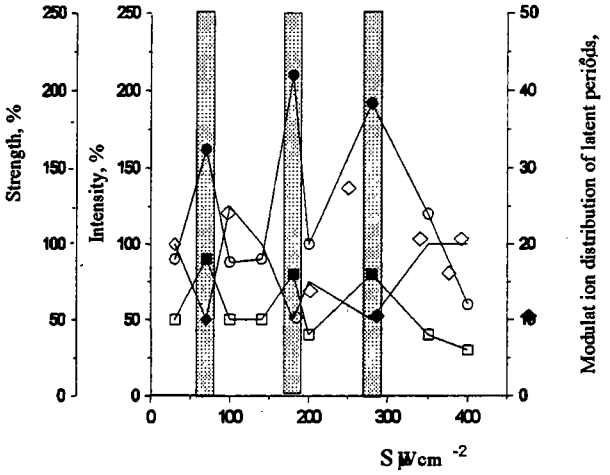
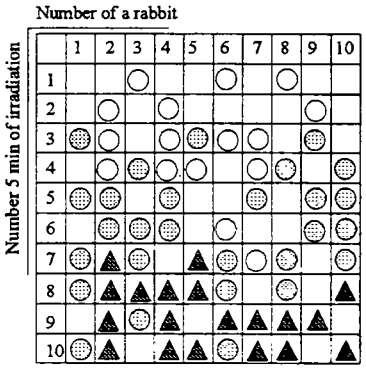
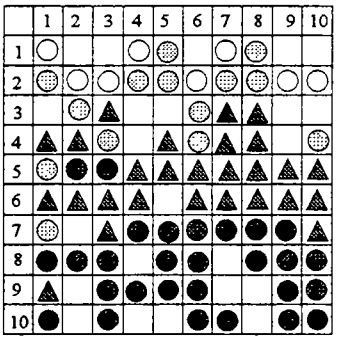


Fig. 3. Dependence of EEG-changes in the parietal region of the brain right hemisphere of a rabbit on PFD. **Note**: strength of the reaction - percentage of the number of cases of reaction to the total number of microwave exposures. Intensity of reaction - excess of the expressiveness of the value analysed over the initial background in percent (100 % - initial background)

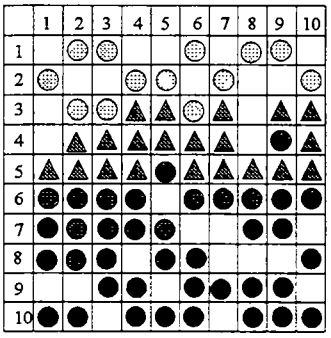
DYNAMICS OF EEG CHANGES ON REPEATED 5-MINUTE IRRADIATIONS OF THE SAME PARAMETERS UNDER VARIOUS INITIAL CONDITIONS



The physiological norm, no-artefacted electrodes



On a background of defective functioning CNS (in 30 minutes the ambassador implantation in bone of no-artefacted electrodes)



At use of metal wires and electrodes, implantanted in bone.

Conditional designations:

- Alfa-activity (reaction - only ambassador 5min. irradiation; On a microwave - effect, accordingly).
- desinchronisation, θ-activity
- Complexes slow and sharp waves.
- Sharp waves activity.

Fig. 4

NEURONAL ACTIVITY UNDER MICROWAVE EXPOSURE

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The investigations presented here are devoted to the topical problem of biological action of electromagnetic fields, in particular, the influence of microwaves on the brain of mammals.

At present, most of the investigations deal with the applied aspects of the problem of biological effects of electromagnetic fields (dosimetric, hygienic, therapeutic). Among the fundamental aspects, somewhat greater emphasis is placed on the analysis of biophysical mechanisms. So far, little attention has been paid to fundamental investigations of the activity of the brain exposed to electromagnetic fields. However, it is precisely those that are bound to play a major role in solving the problem of biological action of these factors, since such investigation make it possible to uncover the genesis and patterns of reactions of the whole organism.

The present investigations are related to the study of inner rearrangements of activity of neuronal populations of the neocortex of the intact brain. The solution of this problem includes the following tasks: 1. examination of the data accumulated in the world about the problem; 2. analysis of EEG under microwave exposure:; 3. clarification of the genesis of EEG-reactions to microwaves; 4. consideration of the frequency indicators of the background activity of cortical neurones under microwave exposure; 5. consideration of evoked activity of cortical neurones under microwave exposure; 6. Study of the pattern of pulse flows of neuronal populations of the cortex under microwave exposure on the basis of an analysis of characteristics of interspike intervals and burst and group activity.

A review of the state of investigations of biological effects of electromagnetic fields over the last 30 years has been conducted by means of the database "Medline". A complex information system of such level cannot a priori be flawless. Specifically: 1. some papers from the journals covered by Medline are absent; 2. the first (priority) Russian works on neuronal activity under microwave exposure are not in this database those they have been published in the journals covered by Medline; 3. not all leading journals of America and Europe are represented there; 4. subdivision by means of key words is not very distinct. Nevertheless, a large amount of information enables one to re-create the general picture of the state of investigations concerning the field in question.

In the past three decades, according to Medline, about 10 thousand papers devoted to biological effects of electromagnetic fields have come out. A considerable share of those, 43.6%, falls on the works concerning microwave action. Among these works investigations of applied kinds (dosimetric, hygienic, therapeutic) are in the lead. Fundamental investigations carried out on the brain, cortex, neurones, and nerves are only 16.2%, including works performed on the brain as a whole - 11.3%, on the cortex, 3.5%, on neurones, 0.2%, and on nerves, 1.1%.

There is a clear-cut trend as far as the number of publications on the biological influence of electromagnetic fields is concerned - from approximately a hundred a year during the sixties to nearly a thousand in a year during the nineties. The share of the works concerned with microwave action was 36.8 - 46.3% in different years, reaching a certain peak in 1976 - 1983. Among those works, the functional activity of the brain in general, of the cortex, of neurones and nerves is considered in 6.1 - 20.6% of cases. Their relative maximum among the total number of publication, was in 1976 - 1983. Their absolute number increases from year to year. At present, the annual number of papers on the problem in question has increased about 15 times compared to the sixties. The greatest quantitative increase (60 - 70 times) is seen in the works on the cortex, while the quantity of papers related to the analysis of microwave action has increased 5 times.

Russian researchers have made an essential contribution to the formulation and development of the problem of biological action of electromagnetic fields. The priority role in the sphere of the experimental study of the influence of electromagnetic fields on the central nervous system belongs to them. In the sixties, according to Medline, at least 25% of the papers devoted to effects of non-ionising radiation on the brain, the cortex, neurones and nerves were published in Russian journals. Probably their real quantity is greater since, unfortunately, not all the papers in those issues were taken into account.

The peculiar features of the effects of non-ionising radiation on the brain are the following. 1. The brain itself contains sources of electromagnetic fields (Kholodov et al., 1987). 2. Electromagnetic fields possess penetrating properties in regard to biological objects (Presman, 1968). The depth of the penetration depends on the kind of tissue and frequency range. Penetrating ability of microwaves concerning the brain mainly confines itself to the neocortex.

Our investigations were carried out on 128 rabbits. If experimentally necessary, electrodes were previously implanted in the brain structures according to appropriate co-ordinates under nembutal anaesthesia. The duration of

electromagnetic exposures was 1 min., which made it possible to record the biopotentials immediately before, during and after the exposure. On application of microwaves the long axis of the animal's head was parallel to the vector E. The wavelength was 12.5 cm and 37.5 cm. The power intensity was 0.1 - 40.0 mW/sq.cm. On the whole, 630 exposures with a registration of EEG and 271 exposures with a record of neuronal activity were conducted. Control records of biopotentials were carried out under identical conditions but without switching on the microwave generator (on the whole, 184 "imaginary" exposures).

Our studies of the influence of microwaves on the central nervous system were begun with the consideration of microwave effects on EEG. It was established that rearrangements of EEG under microwaves do not, in principle, differ from those under other electromagnetic fields or the permanent magnetic field (Chizhenkova, 1967a). The main traits of these EEG-reactions are as follows. 1. As a rule, the changes of EEG were an increase in the number of "spindles" and slow waves. 2. EEG alterations could be described as responses to switching on and off of the factors. 3. In both cases, the changes of EEG develop gradually during 10 - 20 sec. 4. These EEG alterations were generalised in character. 5. Moreover, they were accompanied by changes of the biopotentials in subcortical structures, particularly in the hippocampus, the posterior ventrolateral, anterior and reticular thalamic nuclei, the posterior hypothalamus, the subthalamus, the reticular nucleus of the midbrain tegmentum (Chizhenkova, 1967a, b; Chizhenkova, 1988; Chizhenkova, Safroshkina, 1996).

Some surgical interventions during the investigations (destruction by means of electrical coagulation in the region of the reticular formation of the midbrain, of the posterior ventrolateral nucleus of the thalamus and of the posterior hypothalamus and, moreover, cuts of the trunk of the brain) made it possible to establish that the described EEG-reactions were mainly the result of the immediate action of microwaves on the cortex (Chizhenkova, 1966, 1967).

The purpose of the following stage of the works was to consider spike activity of single neurones of the under microwaves. It was shown that the frequency of background neuronal activity does not display distinct alterations even under intensive radiation (40 mW/sq. cm). No changes of spike activity were detected if the results related to different neurones were summarised. Nevertheless, a separate analysis of different neurones revealed some changes of the spike frequency in 52.4% of the neurones. Among that number, 27.0% the neurones developed greater, and 25.4% smaller, spike frequency. In the control experiments similar alterations took part only in 11.8% of the "false" events, which pointed to the reliability of the observed changes of neuronal activity under one-minute

microwave exposures (Chizhenkova, 1969, 1988). Later works of other authors confirmed the possibility of some alterations of the spike frequency of neuronal background activity of the cortex under microwave exposures, with its increase (Faytelberg-Blank, Perevalov, 1978) or decrease (Lukyanova et al., 1995).

The influence of microwaves on the evoked activity of cortical neurones was more noticeable and uniform than on the background activity. After a one-minute microwave exposure in 85.3% of the events an increase in the number of spikes was observed in the neuronal reactions on the peripheral and central stimulations (Chizhenkova, 1969). The most pronounced alterations were found when using the driving response test (Chizhenkova, 1988).

Our subsequent investigations enabled us to discover that in reality the background neuronal activity underwent serious rearrangements under one-minute microwave exposures, including even those of highly low intensities (Chizhenkova, Safroshkina, 1993, 1996). The point is that the changes developing as a result of microwave irradiation involve more the pattern of spike flows rather than the mean values of spike frequency.

At that stage of the study of microwave effects it was necessary to carry out a wide-ranging mathematical analysis of neuronal spike flows. Moreover, the consideration of spike flows of neuronal populations was more desirable than that of the activity of single neurones. With this approach, individual accidental fluctuations are levelled and dominant changes are emphasised in neurone population. A comparative analysis of the pattern of spike flows of neuronal populations of the cortex was carried out under rather intensive microwave irradiation (40 mW/sq.cm) evoking distinct EEG-reactions and under microwave irradiation of low intensity (0.1 - 0.5 mW/sq.cm), sub-threshold or near-threshold for EEG-reactions.

Microwave exposures of the intensity of 40 mW/sq.cm caused an increase in the mean values of interspike intervals by 7 - 22%. These exposures led to alterations of the characteristics of the burst and group activity too. Microwave irradiation resulted in a reliably decreased number of activity events, in the form of bursts or groups of spikes, by 10 - 23%, which was accompanied by a decrease of duration of the bursts and groups themselves by 5 - 28%.

Microwave exposures of 0.1 - 0.5 mW/sq.cm intensity produced a quite different type of rearrangement of neuronal spike flows. Microwave irradiation reduced the mean interspike intervals by 5 - 16% and, besides, decreased the number of burst and group activity by 7 - 21%. However, inner rearrangements of

the pattern of spike flows under exposures of this intensity were different from the above-mentioned alterations under exposures of rather high intensity. The duration of bursts and groups of spikes increased by 14 - 32%. In consequence, this resulted in an increase of the total share of bursts and groups in neuronal spike flows.

Thus, one-minute microwave exposures induce changes of spike flows of neuronal populations of the cortex. Rearrangements first of all concern the activity events in the form of bursts and groups. The origin of the burst and group activity is determined by the functions of circuits with feedback connections (Chizhenkova, 1986). This kind of neuronal activity is supposed to relate to the encoding of information and to play an important part in the detection of parameters of signals (Chizhenkova, 1992). Hence, during external relative stability of the averaged indices of spike frequency of cortical neurones, essential changes of the integrative functions develop under microwave irradiation.

The effects of microwaves simultaneously include the facilitation of processes of excitement and inhibition in neuronal populations of the cortex. Prevalence of these or other processes depends on the intensity of microwave irradiation.

An analysis of the dynamics of rearrangements of spike flows as a result of microwave exposures made it possible to reveal the parallel participation of three events: 1. reaction to irradiation itself, 2. reactions to switching on and off, 3. fluctuations of the investigated indices of adaptational character. The correlation of these specified events is conditioned by the intensity of microwave irradiation.

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IMMUNOSTIMULATING EFFECT OF HIGH FREQUENCY ELECTRO-MAGNETIC WAVES.

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Most studies concerned with the immunotropic effect of non-ionising radiation were carried out at extremely low frequencies (50-60 Hz), which are widely used in the human activity. An analysis of the effect of weak electromagnetic fields (EMF) of extremely low frequencies (ELF) on the immune system of humans and animals has shown that only prolonged exposure to these fields can change the immune status. Thus, irradiation of people for 9 h at 50 Hz, 10 μT changed neither the blood composition nor the functional activity of T- and B-cell populations or natural killer cells [Selmaoui et al., 1996]. In contrast, a long-term exposure of a biological object (whole body or a cell population in vitro) to ELF EMF causes substantial changes in the cells of the immune system, which is evidenced by the reduced activity of these cells and the exhaustion of central and peripheral lymphoid organs [Walleczek, 1992; Trembley et al., 1996]. The inhibition of cell immunity after prolonged exposure to ELF EMF is one of the reasons for tumour promotion incidences revealed in the epidemiological examinations [Goldberg and Creasay, 1991].

As opposed to the low-frequency waves, which predominantly produce an immunosuppressing effect, microwaves tend to activate immunocompetent cells. This made it possible to use the microwave therapy for correcting the immune status of the human organism in some pathologies. The therapeutic effect of microwaves proved efficient in the rehabilitation of cancer patients. Thus, the microwave therapy is currently used for enhancing the efficiency of surgical, X-ray, and chemotherapeutic methods of tumour treatment [Kabisov, 1997]. In addition, there is convincing evidence that microwaves can act as radioprotectors. Thus, Bundyuk and co-workers [1994] showed an increase in survival of murine fibroblast L cells, that were subjected to gamma-irradiation *in vitro* in a wide dose range (from low to lethal ones) before the microwave exposure. The immunomodulating effect of microwaves is widely used in medicine for treatment of tuberculosis, lung sarcoidosis and thyroiditis [Arzumanov et al., 1997]. It is also known that microwave irradiation (710 MHz, 10 mW/cm^2) eliminates the shifts in the immune system caused by the inhibition of the T- and B-cells functions in patients with resected benign tumours [Zaporozhan et al., 1997].

The effects of EMF radiation of lower frequencies (3--30 GHz) have been less studied. Nevertheless, in the last few years, these radiations were successfully used in clinics. Thus, it was shown by Beletskaya and co-workers that exposure to 3 GHz radiation at a rate of 10 $\mu W/cm^2$ improved the clinical state in 27 patients with gastric and intestinal cancer. Moreover, they reported on the disappearance of metastases in the liver of two patients [Beletskaya et al, 1996]. The workers of this research group showed that the exposure to 12.5-17 GHz waves at a density lower than 10 $\mu W/cm^2$ increased the survival of mice irradiated with lethal doses of X-rays [Makarenko et al., 1996]. These results indicate that the study of the mechanism underlying the effect of microwaves on the immune system is of current interest.

It is known that the anti-tumour activity is largely determined by the secretion of the tumour necrosis factor (TNF), and macrophages and T lymphocytes are the cellular sources of TNF [Vassalli, 1992]. In addition to its cytotoxic activity, early study has demonstrated that TNF may play an immunoregulatory role, enhancing the proliferation of T lymphocytes [Yokota et al, 1988]. The current study was undertaken to examine the effect of weak 8-18 GHz microwaves on the TNF secretion, natural killer (NK) cell activity, and the T lymphocyte proliferative response.

Materials and Methods

Male NMRI mice, 8- to 10- week-old, were maintained under standard laboratory conditions with food and water available *ad libitum*. Exposure was performed using a swinging microwave generator (YA2P-7612, Russia). The frequency range was 8.15-18 GHz, and the average power density was 1 $\mu W/cm^2$. The floor of the exposure chamber (plastic, 25cmx25cm, without roof) was at a distance of 80 cm from the microwave source (trumpet). The shame-exposure chamber was of the same size as the exposure chamber. Peritoneal macrophages and splenic T cells were isolated as previously described (Cifone et al., 1987). NK cell activity was measured by the release of [^{3}H] uridine from target K-562 cells. T cell proliferation was measured by adding 10 μCi of [^{3}H] thymidine for the final 24 h of culture. Culture were harvested and [^{3}H] TdR incorporation was measured on a liquid scintillation counter. A standard cytotoxicity assay for TNF activity was performed using a TNF-sensitive L-929 cell line [Rosenthal and Corsini, 1995]. In parallel assays employing a neutralising antibody (anti-TNF-α monoclonal-Anti-Human TNF-α antibody, Sigma), samples were mixed with a 1:1 solution of 1:1000 dilution of a TNF antibody. Each assay included an internal standard for reference using human recombinant TNF (Sigma).

Results

TNF-α is produced predominantly by the cells of the mononuclear phagocytic lineage, macrophages; in contrast, TNF-β (lymphotoxin) is produced predominantly by T lymphocytes. While TNF-α and TNF-β share very similar biological profiles and receptors (Vassalli, 1992), the results described in this study will apply to TNF-α and TNF-β, which will be hereafter referred to as TNF. Figure 1 shows the kinetics of the enhancing effect of microwaves on the TNF secretion by macrophages as a function of exposure duration (from 0.5 h to 7 days) in animals irradiated with 10 GHz. The increase in the macrophage cytolytic activity was observed only when the exposure duration was at least 3 h. The maximum activation of TNF was observed after the 5 h exposure. The level of TNF secretion increased continuously with the exposure duration from 10 h to 3 days, being twofold higher than the control value. A further increase in the exposure duration reduced the capacity of electromagnetic waves to enhance the secretory activity of macrophages. After a 5 day exposure, the cytotoxicity of macrophages approached the control level, and the irradiation of mice for 7 days led to the inhibition of TNF production.

It should be noted that the exposure to a low-frequency electromagnetic field does not increase the TNF production in peritoneal macrophages. Thus, prolonged irradiation of mice with 60 Hz waves did not affect the TNF secretion in these cells [Tremblay et al., 1996]. It was also shown that a 3-day *in vitro* irradiation of peripheral blood lymphocytes with 50 Hz electromagnetic waves induced the inhibitory effect on the TNF secretion [Jonai et al., 1996]. However, even a short in vitro exposure of blood lymphocytes to a radiofrequency waves increased the spontaneous TNF secretion by these cells [Lagalla et al., 1996].

The activation of TNF production revealed in this study suggests that microwaves can improve the cellular immunity in some pathologies, including carcinogenesis. In this connection, it was important to study the distant effects of microwaves. We studied the TNF secretion by peritoneal macrophages and splenic T lymphocytes over a period of 72 h after the exposure of animals to 8-18 GHz waves at a rate of 1 $\mu W/cm^2$. The exposure duration was 24 h. Figure 2 shows the level of spontaneous and lipopolysaccharide-stimulated cytotoxic activity of peritoneal macrophages from intact and irradiated animals. It is seen that the exposure of mice for 24 h increases the TNF production in macrophages of irradiated animals, and this increase persists over 3 days after the termination of exposure. The activation level is the same as after the 5 h exposure (Fig. 1).

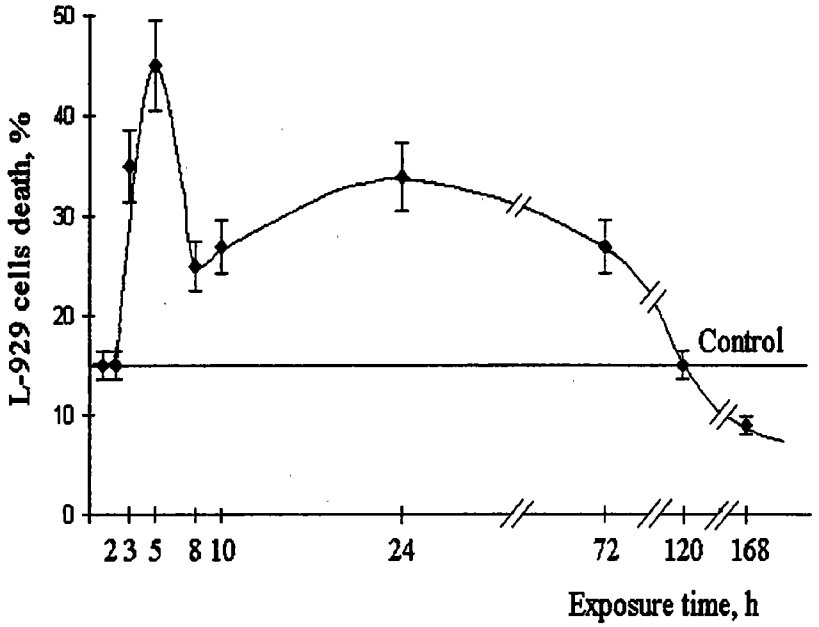

Figure 1. TNF production in peritoneal macrophages from mice after their exposure to 10 GHz microwaves at 1 $\mu W/cm^2$. Data are expressed as the percentage of target L-929 cells death. Each value is mean ±SD from five mice. The time of exposure is shown on the X-axis. Error bars are ± SD.

Interestingly, the microwaves application is even more efficiently stimulated the endogenous production of TNF than LPS, which is one of the most frequently used owing to its stimulatory potency [Vassali, 1992].

It should be noted that the effect of microwaves was also observed in LPS-stimulated macrophages, although it was less pronounced than in intact cells. In these experiments, it was also found that microwaves stimulate the cytotoxic activity in splenic T cells (Fig. 2). The extend of activation was much higher in T lymphocytes than in macrophages; however, three days after the termination of exposure, the secretory activity in this cell population was only slightly higher than the control value. It can be concluded that the postirradiation kinetics of TNF synthesis in the two main cell populations was different.

Natural killer (NK) cell are characterised by their ability to lyse susceptible tumour cells or virus-infected cells without prior sensitisation. It is noterworthy

that another aspect of TNF activity, namely its ability to enhance NK cells – mediated tumour cell lysis, have been revealed (Stensed et al., 1987).

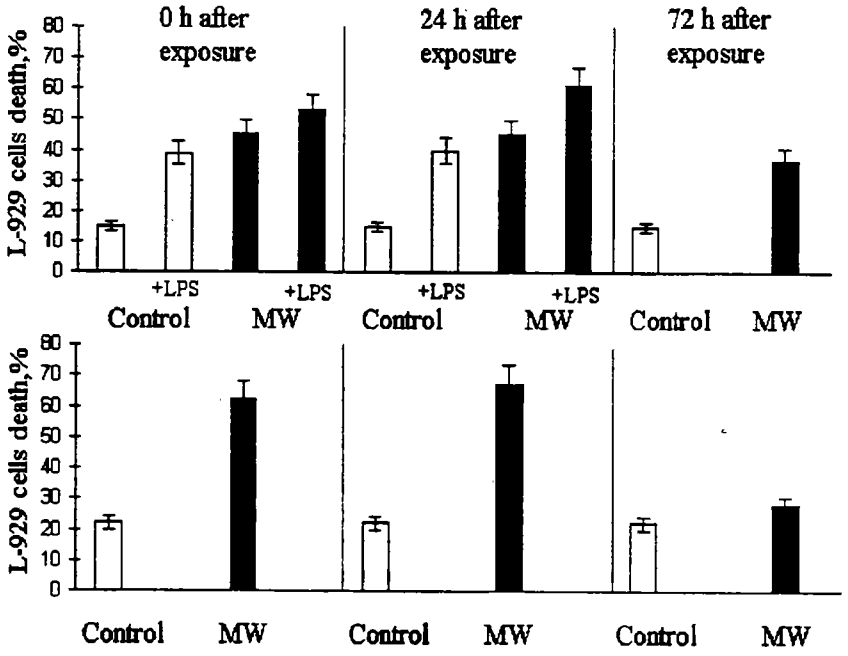

Figure 2. Long-term effect of whole body irradiation with 8.15-18 GHz at 1 μW/cm^2. TNF production in macrophages, upper panels; and TNF production in T cells, lower panels. Where necessary, 1 μg/ml LPS was added to cell cultures. Data are the mean ±SD quadruplicate determination from 5 mice.

In the present study we showed that whole-body microwave exposure enhanced NK cells activity in spleen from irradiated mice (Fig. 3). If, as has been suggested, NK cells are important in the natural resistance to tumours, it may be that some part of the anti-tumour effects of microwaves is mediated by the enhancement of NK cell activity. Taking into account the long-term effect was more efficient as compared with immediate stimulation of NK cell activity, one can conclude the existence of different MW-induced stimulating patterns for various types of cellular immunity.

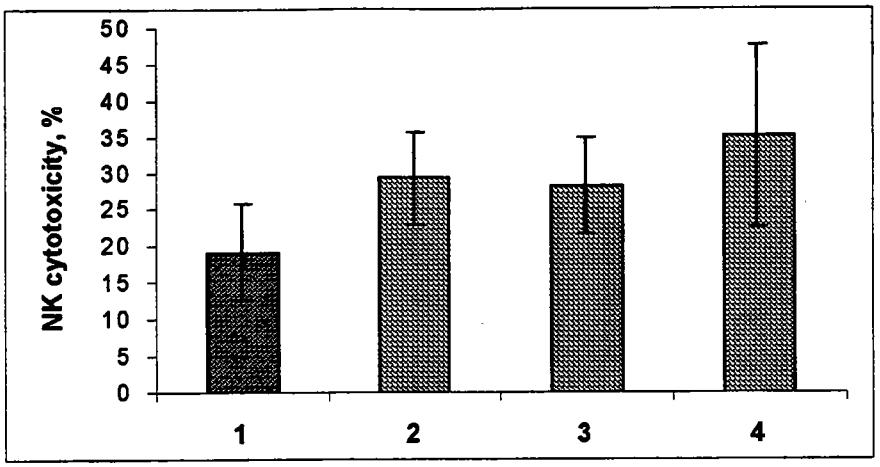

Figure.3. The effect of microwaves (8.15-18 GHz, 1 $\mu W/cm^2$) on splenic NK cell activity.

K-562 cells were labelled with 3-6 mCi/ml [^{3}H]- uridine and cytotoxicity effect of NK cells from nonadherent splenic lymphocytes by the release of radioactivity from target cells (ratio effector /target 25:1) was measured. Data are given in percentages of cytotoxicity as the mean value of $\pm$ SD guadruplicate determination from six mice. 1 - control; 2 and 3 - 24 h and 48 h whole-body exposure, respectively; the experiments were conducted immediately after microwave treatment; 4 - 48 h exposure, the experiments were conducted 24 h after microwave treatment.

Discussion

We believe that the increase in TNF production and persistence of this effect over a period of 72 h after the termination of exposure indicate the stimulation of the immune system. This suggestion is confirmed by the measurements of stimulated and unstimulated splenic T lymphocytes proliferation (Fig. 4).

Immediately after the exposure, the spontaneous activity of T cells sharply increased, indicating a substantial enhancement of the cellular metabolism. The proliferative index, which is a measure of cell response to the mitogenic stimulus, did not differ from the control. One day after the termination of irradiation, a significant increase in the immune response of T lymphocytes isolated from the spleen of irradiated animals was observed. Three days after the exposure, the

proliferative response of these cells did not differ from the control value, and was consistent with the decrease of the microwave effect on the TNF secretion in T cells (Fig. 2).

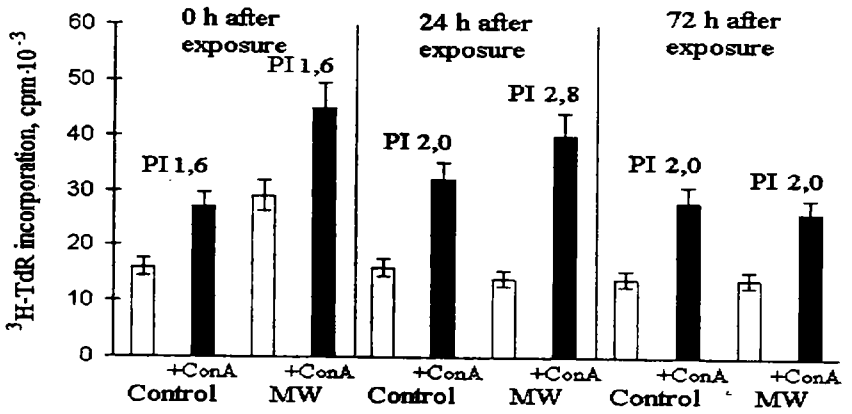

Figure 4. Long-term effect of microwaves (8,15-18 GHz, 1 μW/cm^2) on splenic T cell proliferation. ^{3}H-thymidine incorporation was assessed, and data are expressed as the mean ±SD quadruplicate determination from three mice. The proliferative index (PI) is determined by the ratio of stimulated (with 5 μg/ml ConA) to unstimulated ^{3}H-TdR uptakes.

Interestingly, the irradiation of T lymphocytes, line CTLL-1, for 4 h with 60 Hz amplitude-modulated 450 MHz electromagnetic waves inhibits the cytotoxicity of T cells towards the target cells [Lyle et al., 1983]. However, the intensity of exposure in this study was three orders of magnitude higher than in our experiments.

The activation of TNF synthesis by the electromagnetic field may indicate either an increase in the protective function of the organisms or post-irradiation disturbances of the cellular immunity. Among cytokins produced by the cell, the TNF is characterised by a peculiar system of regulation of its own synthesis. TNF is synthesised by cells in response to a number of stress conditions: thermal shock, viruses, and ionising radiation [Arrigo, 1990; Sherman et al., 1991; Feduchi and Carrasco, 1991]. It is known that the TNF can produce both a protective and a destructive effect on the cell. Thus, injection of TNF protects the organism from the lethal effects of ionising radiation [Neta et al., 1988] and hyperoxia [Tsan et al., 1990]. It is believed that one of the possible mechanisms for the protective effect of TNF is the stimulation of additional synthesis of this cytokin by the oxidative

stress. In this case, the regulation proceeds by the positive feedback mechanism. The possibility that the TNF plays a protective role under stress conditions due to its ability to activate its own synthesis is confirmed by the experiments with the TNF-sensitive L-929 cells: when resistant mutants of L-929 cell line were selected by repeated exposures to TNF, they were found to synthesise TNF [Rubin et al., 1986].

Thus, we have demonstrated that exposure of animals to a weak electromagnetic field stimulates the cellular immunity. It is evident that two cell populations, which are the main TNF producers in the organism, possess different sensitivity to microwaves. These different kinetics may be explained by the highest accumulation of TNF-α mRNA in stimulated cells; in contrast, TNF-β mRNA appears much more slowly and much more lower releases [English et al., 1991]. The effect of the electromagnetic field was more pronounced than that of LPS. The mechanism whereby microwaves enhance TNF production, NK cell activity, and mitogen-induced T cell proliferation is not clear. TNF triggers the secretion of most if not all mediators, including IL-1 and others cytokins, and extends the range of its action [Heller & Kronke, 1994]. Since cytokins were implication in having a vital influence on the specific functions of the immune cells, analysis of cytokine profile in cells from irradiated animals is also essential. Further study is needed to elucidate the mechanism of the immunomodulating effect of microwaves.

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EEG SPECTRAL PATTERNS CHANGE IN AWAKE ANIMALS UNDER EXPOSURE TO A LOW-INTENSITY ELECTROMAGNETIC UHF FIELD

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There is no doubt that the problem of influence of electromagnetic fields (EMFs) on humans and animals is topical. However, the neurophysiological mechanisms of such influence are still largely unknown. One possible way of EMF (UHF range) action on CNS seems to be through the mediation of the auditory sensory system (Tigranyan, 1988; Guy, Chou, 1975; Lin et al, 1978; Lin, 1980; Wilson, Jones, 1985). But in most experimental studies exposures of high intensity (higher than the thermal threshold) were used. Low-level EMF effects on CNS, whose action can not be explained by the thermal effect alone, have not been investigated rather little.

In recent years some results have been obtained on awake animals which reveal a possibility of low-level (peak power density PPD = 0.5 mW/cm^2) electromagnetic (EM) pulses influence on the response amplitude of the cortical auditory and sensory-motor fields evoked by an acoustic stimulus (click). Hystochemical studies have shown changes in the metabolic activity of auditory and somatosensory centres of the rat's brain under exposure to the same intensity pulse-modulated EMF of UHF range (Krasnoshekova et al, 1995).

The goal of the present study was to investigate how low-level modulated UHF EMFs influence the EEG spectral characteristics in cats, and to make an experimental comparison of EMF and acoustical stimulation effectiveness on the EEG parameters under analysis.

Methods

Three awake intact animals and 2 cats with implanted electrodes in the skull bone were used in the study. During the experiment a cat was placed in a shielded soundproof chamber (weakening of sound at frequencies over 100 Hz was more than 70 dB). TV was used to observe the animal's behaviour during the experiment. The acoustic stimulus intensity was 70 dB in relation to $2*10^{-5}$ N/m^2. The EMF flow density with the carrier frequency of 980 MHz did not exceed 50 $\mu W/cm^2$ near the animal's head.

We used 2 types of modulated signals for EM stimulation. At the first stage of investigation we applied pulse-modulated microwave irradiation consisting of consequent EM pulse bursts. The pulse duration was 2 ms, pulse frequency in a burst was 1000 Hz, burst frequency was equal to 7 Hz. At the second stage experiments we used both EM and acoustic pulse modulated stimulations. The signal formation rules were the same for both EM and acoustical stimulations (Degtyarev, Cvetkov, 1996). For the calculation of modulating frequency values, we took into account the basic maximum range of the background EEG of the animal in an active awake condition. It was usually found in the 23-29 Hz range. That is why the selected initial frequencies were f1=27 Hz (own waves) and f2=12 Hz (break frequency relative to invariant frequency f0=18 Hz, $f0=(f1+f2)^{1/2}$.

EM and acoustical signals were presented in the following order: 1 minute of stimulation, then 1 minute without any exposure, and so on during 20 minutes. We performed these experiments 2-3 times per week.

At stages 1 and 2, EEG was registered by carbon electrodes from the skin of the head. The active electrode was placed in the vertex area, while the referent one on the dorsal surface of the auricle.

At stage 3 the silver spherical electrodes were implanted in the skull bone of 2 cats under anaesthesia above the following fields: AI, parietal cortex (field 5) and sensory-motor cortex. The referent electrode was implanted in the frontal sinus. For these animals the second type of EM modulation was given. After 12 experiments of EEG recording (6 experiments were without exposure and 6 experiments were held under EMF influence) the cats were treated with kanamycin sulphate (200 mg/kg i.p.) daily for 3 weeks. After 2 weeks of registration (12 experiments according to the same pattern) their cochlea were taken for histological analysis..

In each trial the spectral patterns of EEG were analysed in the initial background activity at the beginning of the experiment (before exposure), 1 minute after the beginning of an exposure and finally after the exposure. Accordingly, we analysed EEG 1 minute after the beginning of the exposure at stage 1, and at stages 2 and 3 – in the first pause between signal segments i. e. without any irradiation.

For estimation of the EEG dynamic spectral patterns during the trial we used coefficients of relative spectral power (K). Usually 2 types of coefficients were used: the relation of the averaged spectral PPD (ASPD) of the range in question to 1) the ASPD of the background EEG most emphasised range at the

start of a trial, and to 2) the ASPD of the whole analysed field of frequencies (1-50 Hz).

In order to define the ASPD of different frequency bands we used a special index (I). The I allowed to estimate a relation of the spectral power of the 2 ranges: a range which was represented extremely in an initial background activity («typical» range) and an («investigated») range in which we expected to find a change of ASPD or its absence. The index was calculated as follows:

$$I=(Sx-Sn)/(Sx+Sn),$$

where Sx is the ASPD of the investigated range, Sn is the ASPD of a typical range in the initial background frequencies.

The reliability of changes in K coefficients during and after EMF exposure, as compared with the initial K in the background EEG before irradiation, in all experimental series and in all animals was estimated by using Wilcockson nonparametric rank criterion. The reliability of I transition to the positive area of values after 1 minute of exposure and after the signal was over, compared to the initial value, was estimated with Fisher nonparametric criterion.

Results

The irradiation lasted during 1 hour. EEG was registered not only before, after 1 minute and after the end of irradiation, but in addition every 10 minutes of the signal action and 10 minutes after the signal was switched off. The K coefficients were calculated for the 6-8 Hz band (including the fixed frequency of the signal - 7 Hz) in relation to the whole range under study, and to the adjacent ranges. It was shown that after a minute of exposure a reliable ($Po<0,01$) increase already occurs in the relative power in the 6-8 Hz band, both in relation to whole and to the adjacent ranges. Later, during 1 hour of irradiation and even 10 minutes after the end of EMF exposure the revealed correlation is preserved, even if changing its value. The coefficients K difference has a negative value in most cases, which is the evidence that the K for 6-8 Hz band under exposure exceeds the value of K for this range for the EEG registered before the exposure. After EMF is switched off the power prevalence of the 6-8 Hz range remains for at least another 10 minutes.

The results obtained at stage 1 of the study point to a possibility of weak EMF influence (PPD up to 50 $\mu W/cm^2$) on EEG spectral characteristics of an awake animal brain. A reliable increase of the K coefficients takes place in

comparison with the background K for the range that includes the frequency contained in the EM signal – 7 Hz. The existence of the effect after switching EMF off denies the possibility of directly induced stimulation on the registered electrical brain activity. Nonetheless, to exclude such possibility we changed the signal structure and the procedure of the experiments.

At stage 2 we used EMF whose pulse modulation frequency was changed during the trial. The goal of the given experimental series was not only to confirm a weak EMF (of UHF band) influence on the electric brain activity but also to compare the effects of EM and acoustical exposure. According to this, we conducted 15 trials with exposures and 10 control trials without exposure (false exposure) on 2 cats. In the experiments with false exposure, EEG was registered at the same time as in the case of using acoustical or EM stimulation. To escape the development of habituation of the animals to any signal, the experiments were alternated in series of 5 – with sound, EMF and without exposure.

An analysis of EEG spectrum (from the head skin surface in the vertex area) revealed that the beta band usually prevailed in the background activity in the beginning of trials. In one cat the most powerful spectral patterns of EEG appeared in the 23-29 Hz range, in the second cat in a broader field of frequencies - 25-40 Hz.

In the false exposure trials the spectral power patterns of the initially expressed range could be decreasing. At the same time we observed an increase of power in the delta-band. In addition an increase in the spectral patterns power in the field of 12-18 Hz occurred in the trials with acoustical and EM exposure. This range of the background EEG spectrum is usually barely expressed. The calculation of the coefficient K of the 12-18 Hz range has shown its reliable increase ($P<0,01$) under both EM and acoustical stimulation.

At this stage of our investigation we tried to estimate the dependence of effectiveness of the exposure applied on the initial parameters of EEG spectrum. With that goal in view, calculation of the I was made for the 2 ranges: the 12 – 18 Hz, which was under study, and a cat's typical initial background EEG range.

In the trials with false exposure the I used to have a negative value both at the beginning of a trial and after it was over. This means that in the trials with false exposure the spectral power of the typical for the cat range of 25-40 Hz during the whole trial was usually greater than the power of the 12-18 Hz range. There were no transitions to the positive area of values in the trials of this series. Thus, in the

trials without exposure the typical range power prevailed over the power of the 12-18 Hz range. This correlation was preserved throughout the trials in both cats.

In «K» cat, the I of 12-18 Hz went to the positive value area under sound action already after 1 minute after switching off the signal in most cases. The transition of the I to the positive area in this animal after 1 minute of acoustical exposure is reliably faster ($P<0,01$) than in the trials with false exposure. That means that the spectral power of 12-18 Hz range usually exceeds the power of the 25-40 Hz range. In the other animal such a reliable effect appears later ($P<0,01$), after the sound exposure is completely over. At the same time in first cat the transition of the I into the positive area becomes unreliable after the sound exposure is completely over. Hence in «K» cat at the end of the trials, the ASPD correlation of the 2 analysed ranges approaches to the initial form (before stimulation). It can be supposed that in this animal the habituation to acoustical exposure developed in the end of the trial which resulted in the disappearance of the effect observed after 1 minute of stimulation.

In the series with EM stimulation in both animals the I becomes positive already after 1 minute after the beginning of irradiation. The spectral power of the 12-18 Hz band reliably exceeds ($P<0,01$) the spectral power of the typical range (25-40 Hz for one cat and 23-29 Hz for the other). After the EM stimulation is completely over, the frequency of the I transition into the positive area decreases and becomes unreliable in both animals. In most cases the I has a negative value. Thus, the maximum effect of the I change and its reliable transition to the area of positive values occurs 1 minute after the beginning of EM stimulation. A further decrease of the expression of this effect, observed after the exposure was over, as was the case with acoustical stimulation in one cat, could be caused by habituation to such exposure. Animal adaptation to weak EMF is well known, and so is cumulation. It should be underlined that we observed no cumulative effect in the I dynamics. This appears to be caused by the alternation of the used types of stimulation and trials without exposure.

The use of the I for estimation of changes in the brain EEG of awake cats made it possible to determine a similar tendency in ASPD redistribution both in the studied 12-18 Hz range and the one typical for a given cat under exposure to acoustical and EM stimulation. At the same time some differences in the effects of the used stimulation action could be caused by individual sensibility of the animals.

For control of the revealed effect such an analysis of the spectral power changes was made for other ranges. In both animals the I values were calculated

for the ranges of 5-8 and 8-12 Hz. In all the cases the I was calculated in relation to the most typical range for the initial background activity in every cat. In none of the experimental situations did we observe any reliable transition of the I into the area of positive values.

Similar results have been obtained for the I of the 8-12 Hz range. This allows us to conclude that the redistribution of ASPD is interconnected only with the 12-18 Hz range out of the three analysed at this stage. The redistribution is expressed in the ASPD decreasing in the most representative range of the initial background activity that is typical for every animal and the 12-18 Hz range ASPD increasing in both cats. Such reliable redistribution occurs both under EM exposure and under acoustical stimulation.

For comparison of the results obtained by using EM signals of 2 types we calculated the I in EEG spectrum registered under EM irradiation of the first type. The I was determined for the 4-8, 8-12 and 12-18 Hz ranges in relation to the typical range of 21-26 Hz of the initial background EEG in this animal. It was found that the I of the 4-8 and 12-18 Hz ranges reliably more often shows positive values after the end of EM stimulation than at the beginning of each trial before EM exposure. The I of the intermediate range of 8-12 Hz was usually negative at the beginning of a trial, after 1 minute and after the end EM irradiation. We have not revealed any reliable change of its sign. Thus, under a pulse-modulated EM signal exposure of the first type, a reliable redistribution of ASPD occurred in the range expressed in the initial EEG and the ranges of 4-8 and 12-18 Hz. At the same time only the 4-8 Hz range includes the 7 Hz frequency contained in the signal.

An analysis of the changes of EEG spectral patterns has shown that EM influences of PPD up to 50 μW/cm2, both with a fixed and with a changing frequency of modulation lead to a reliable change of the power correlation of the range of 12-18 Hz and the initially most expressed range in the background activity. If the signal has a constant frequency of modulation of 7 Hz, the relative power of the range including this frequency also reliably increases.

An analysis of EEG spectral parameters registered from the skull bone above the auditory and associative fields of the neocortex has revealed some peculiarities of their change under EMF exposure. In the auditory cortex a reliable increase of the I and its transition into a positive area of values occurs after 1 minute of EM exposure for the 8-16 Hz range. After the end of EM exposure the spectral power increases in a broader range of 4-16 Hz. In the parietal associative cortex the I reliably passes into a positive area of values in the 12-16 Hz range after 1 minute of EMF action, after the end of the exposure the I increases and the

spectral power in the range 8-16 Hz correspondingly increases too. The smallest number of changes was observed of EEG spectral parameters under EMF action in the sensory-motor cortex. Here the I reliably increased in the 12-16 Hz range after 1 minute of exposure. In this case the I did not pass into a positive area, i.e. the spectral power of the 12-16 Hz range did not exceed the power of the initially expressed field of 36-44 Hz in these animals.

Thus, the observed changes of the I and correspondingly the changes of spectral patterns power of EEG registered from the skull bone above the auditory and associative fields of neocortex are similar on the whole with the I dynamics in the case of EEG registration from the skin surface in the vertex area. With the use of both methods of registration under the influence of pulse-modulated EMF, redistribution takes place between the initially expressed range in the background EEG and the range of 12-18 Hz. It is noted that out of the 3 tested fields of the neocortex this transformation of the spectrum power is more expressed in the auditory cortex.

After 3 weeks of kanamycin administration (15 injections) which is an antibiotic destroying the hair cells of Cortii organ we analysed spectral patterns under similar EMF exposure. A histological analysis of the hair cells shows that as a result of kanamycin treatment mainly the outer hair cells are damaged in the basal part of the cochlea Cortii organ. These cells specialise in the perception of high frequency acoustical signals.

A reliable change of the I under EMF exposure remains only in the parietal cortex. Here the I increases after 1 minute of stimulation in the 12-16 Hz range. In the rest of the cases we have not found any reliable changes in the range under study. Hence, irradiation of animals after outer hair cells destruction does not lead to those reliable changes of EEG, which were observed in the 12-18 Hz range in the intact animals.

On the whole the results conform to the assumption of one of the possible ways of EMF influence on CNS through the auditory sensory system.

Discussion

It should be noted that a possibility, in principle, of EMF influence on the bioelectrical activity of the brain (as well as EEG) has been investigated many times (Vasilevskii et al, 1982, Lebedeva, 1995, Luk'yanova et al, 1996, Suvorov et al 1987, Bell et al 1994). However, only in recent years the possibility of changing of some EEG waves representation under EMF exposure, and a connection of the

observed changes with the frequency characteristics of applied exposure have been shown in a few studies (Bell et al, 1994).

In the experimental animals under EMF exposure of both modulation types a redistribution of spectral power occurred between low and high frequency fields of the beta-band, as both ranges the initially expressed (from 20 to 40 Hz in different animals) and the one revealed under EM irradiation of 12-18 Hz belong to the beta-band in cats. An EEG analysis in humans has shown that if in some experimental situation an intensification of a weak rhythm occurs then the initially more expressed rhythm is usually depressed (Livanov, 1984). The application of the I has allowed to estimate the interconnection of the spectral power change of the 2 component parts of the beta-band and to evaluate the reliability of the observed transformations.

As a result we observed a reliable transition of the I to the positive area after 1 minute of EMF action. Such a short time of EM exposure to produce the effect is hardly consistent with the common opinion of a necessary long EMF exposure to produce brain electrical activity changes or behaviour changes. However, in recent studies (Luk'yanova et al, 1995; Moiseeva, 1996) it was revealed that about half of the tested cortical neurones of sensory-motor and visual fields in rabbits can change their pulse frequency under EMF exposure (PPD 300-500 μW/cm2) with a latent period of about 12 s, while an effect in EEG appears in 10-25 ms at PPD less than 300 μW/cm2 (Luk'yanova et al, 1996).

Thus, the opinion on the necessity of numerous and long EMF exposures to obtain changes in CNS and particularly in EEG has its origin in the use of quite powerful fields (more than 1 mW/cm^2) and the application of constant EMFs. The data of comparative experimental investigations point to the fact that EMFs with PPD 20-50 $\mu W/cm^2$ act more markedly on EEG parameters, conditioning behaviour and motor activity of animals than EMF with PPD 500 $\mu W/cm^2$ and more (Asabaev et al, 1972, Rudnev et al, 1976). Some investigators (Bell et al, 1994) suppose that the ability to detect weak EMFs is a common physiological characteristic of living beings.

The influence of EMFs significantly increases with the application of intermediate or modulated signals (Bychkov et al, 1972; Galeev, Zhuravlev, 1995; Togskaya, Gordon, 1971). Moreover, the effectiveness of EMF influence depends on the frequency and energy windows (Gapeev et al, 1996; Luk'yanova et al, 1996; Aidy, 1980) . According to the theory of stochastic resonance (Makeev, 1993), weak rhythmical EMFs, whose power is markedly lower than the power of the brain EMF, can promote the transition of a biosystem from one condition to

another by modelling the behaviour on the whole and the bioelectrical activity in particular.

A similar redistribution of ASPD in the animal brain electrical activity under EMF exposure and acoustical stimulation demonstrates a certain likeness of the neurophysiological mechanisms of these effects. Accordingly, a question arises of the connection of the observed effects with the frequency parameters of EMF. The comparison of the results of EMF exposure with the constant frequency of modulation of 7 Hz and the changing modulation frequency (the range of change of low frequency in the 12-18 Hz signal) allows to some extent to answer this question. In both cases a reliable upward redistribution of ASPD takes place in the 12-18 Hz range. However, if an EM signal has fixed frequency characteristics which do not coincide with this range, we can additionally observe a reliable increase of ASPD of the range including a fixed modulation frequency of the EM signal.

Almost in the same range Suvorov (Suvorov et al, 1988) noticed an increase in the EEG activity synchronisation registered at the same time in the sensory-motor cortex, lateral hypothalamus, hippocampus and the medial centre of thalamus under long EM irradiation.

Thus, the presented experimental data on the whole demonstrate that the auditory sensory system possibly plays a role in the neurophysiological mechanisms of UHF EMF influence on the CNS.

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EFFECTS OF LOW-LEVEL ELECTROMAGNETIC EXPOSURE ON BEHAVIOUR AND STATUS OF ACOUSTIC RECEPTORS IN CATS

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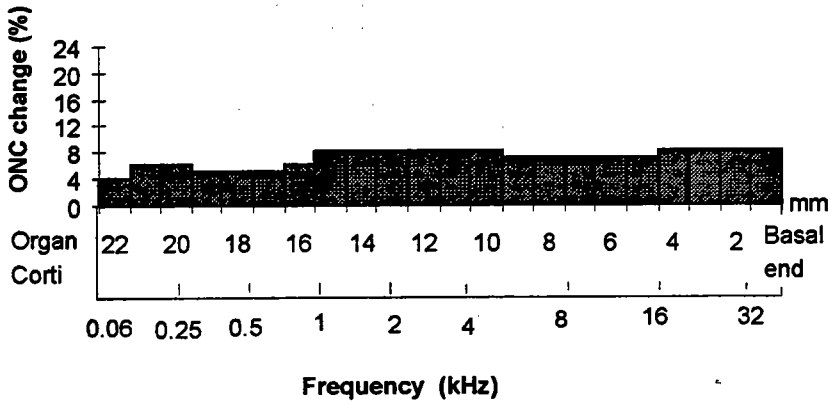
In our days a great deal of attention is paid to the study of effects of low-level electromagnetic field (EMF) on behaviour and EEG activity of the brain. Of major importance are the parameters of EMF modulation, as at low intensities it is the changes of modulation frequency that can condition the EMF effect on the body, especially if the modulation values fluctuate within the limits that are biologically significant for the body. In addition, at low-intensity EMFs the perception mechanisms of EM signals can be studied in more detail, as in that case the body adaptation mechanisms are not yet active and the EMF-induced cumulative effect is yet minimal.

We studied the influence of pulsed modulated EM exposure on the behaviour and status of the Corti organ receptor cells in cats (8 animals). Square pulses with the carrier frequency of 980 MHz complied with the frequency which changed by 1 Hz every 2 s within the 1-10 Hz or 20-40 Hz interval. The entire frequency change cycle lasted 42 s for the first frequency interval and 84 s for the second. The pause between the pulses was 30 s. EM exposure conditions were specially chosen for these experiments on the basis of the data on the parameters of EEG activity of the cortex during aggressive behaviour in cats.

Observation of the animal behaviour during 1 hour of EM exposure (32 pulses) showed a statistically reliable increase in the number of behaviour reactions from the very first day. Moreover, the share of vocalisations and reactions of intercourse increased percent, and the animal movements towards the source of irradiation appeared. The EMF - induced reactions were registered at the beginning and at the end of each frequency change cycle and later analysed. It was shown that the probability of such reactions was 0.5-0.6 for 20-40 Hz and 0.1-0.4 for 1-10 Hz pulse modulated frequency ranges. The rate of habituation was lower when 20-40 Hz EM exposure was used than for 1-10 Hz one (fig.1). The responses to the presence of EMF were not specific (head movements, postural changes, getting up, grooming, locomotion) and only 10-40% of all reactions were orientations to the source of irradiation. The type of non-specific reactions was changed during EM stimulation. The head movements were mostly similar to shaking off, the postural changes were like shrivelling, grooming suddenly began at switching on an EMF and abruptly broke of when it was switched off.

Fig.1. The percent of OHC change in the normal organ Corti



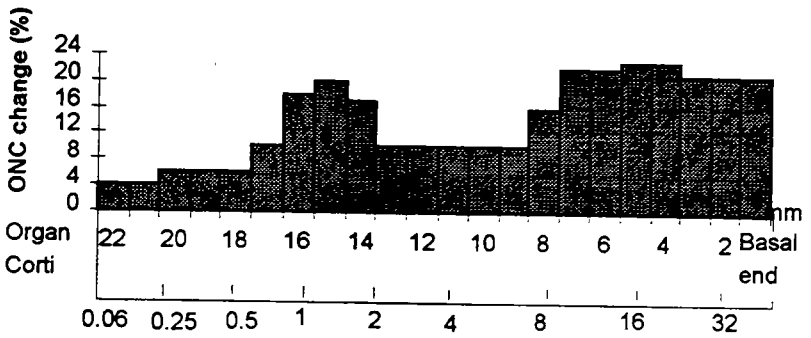
During EM exposure the animals were tested for response to species-specific vocalisations. It was established that after acute discontinuation of these reactions, which were non-specific like the reactions to EM stimuli, there was a statistically reliable increase in the frequency of responses to vocalisations against the EM exposure background.

For 2 animals the following experimental procedure was used. At first the EMF - induced reactions to one vocalisation were extinguished, and then we switched on EMF and tested the animals' reactions to the same sound signal. It was shown that multiple repetition of this procedure resulted in disinhibition of the responses to vocalisation (fig.2). It was most effectively manifested at pulse modulation frequencies within the 20-40 Hz range. Moreover, the use of a complex stimulus (vocalisation + EM exposure) showed that any change in the pulse modulated frequency of the EM signal led to disinhibition of the extinguished reactions to this complex stimulus. Agonistic vocalisations were the most effective manifestation of such phenomena.

After EM exposure both cochleae of the three experimental and two control cats were prepared for future analysis. The cochleae were fixed by perfusion with glutaraldehyde (5%) and paraformaldehyde (4%) in phosphate buffer PH 7,4. Then decalcination was obtained and the entire modiolus, with the organ of Corti, was carefully dissected from the cochlea. After dehydration the whole preparations of the three turns (basal, middle and apical) of the organ of Corti, were examined by

phase contrast microscopy for cytological analysis. Preparation artefacts were excluded by comparing the materials of the subjects and controls. The organ of Corti showed four bands along its length. Three of these bands corresponded to the three rows of the outer hair cells (OHC), the fourth band belonged to the inner hair cells (IHC). In the present investigation OHC in each of the three rows were counted and calculated for each of the three turns. We compared the OHC-changed percent in the experimental animals with the controls. The data on the relation between the length of the basilar membrane and the frequency localisation were borrowed from Schuknect (1).

Fig. 2. The percent of OHC change in the organ Corti after electromagnetic influence



The OHC of the organ of Corti show a very strong structural differentiation. In the basal turn they have a short cylindrical form and become gradually longer towards the apex of the cochlea. At the base they sit on the supporting cells. The cell nuclei are normally localised at the base. A typical feature of the organ of Corti is the regularity of the OHC pattern.

Morphological changes were observed after EMF exposure. The level of the nuclei of the OHC showed a number of swollen nuclei, one of the typical early structural alterations (2). The normal basally located nucleus can sit in the subapical zone. As a consequence the OHC, particularly in the third row, show an irregular distribution pattern.

In all the cochleae of the control animals such morphological changes were observed too but their highest number in the controls was not more than 7,5% (fig.3). As no changed cells could be found in these parts of the turns, which were undamaged, the true percentage of such changes was probably even smaller. In comparison with the control animals, all the EM exposed animals showed a greater number of changed cells - about 22 % in the basal turn (8 mm from the base) (fig.4). It is in this area that the cells accepting the frequencies from 32 to 8 kHz.

In the middle turn (13 mm from the base, frequency range 8-2 kHz) there was a smaller number of the OHC-changed cells - about 8%. The mean value of the OHC-changed cells in the apical turn showed a peak at the 15 mm (18%). The site of the OHC-changed peak in this turn was in agreement with the frequency area 1,5-0,7 kHz (fig.4).

The results of the present study correlate with our earlier works. According to those, different ultrastructural changes of the OHC in the rat organ of Corti were detected, particularly in the basal turn after EM exposure (3). After EMF exposure, an increase in the cytochrome oxydase activity in acoustic centres of the rat brain was revealed (4).

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COOPERATIVE INFLUENCE OF THE CIRCULARLY POLARISED MILLIMETER WAVES AND ETBR ON E.COLI CELLS

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Abstract.

In our work the research on the action of polarised electromagnetic fields (EMF) of millimetre wave (MMW) range on E.coli cells was carried out. Earlier it was shown, that for eukaryotic (Wistar rat thymocytes) and prokaryotic (E.coli) cells the effectiveness of the influence of the right and left-handed polarised EMF of the MM range is different. In order to explain these effects a hypothesis was advanced connecting the observed selectivity in the effectiveness of the influence of polarised EMF with the spiral of DNA molecule. It is known, that such substances, as EtBr (ethidium bromide) are intercalators for DNA and are capable of changing its helicity, therefore in the present work the investigation of the action of polarised waves (F = 51.76 GHz, time of exposure 10 min, power density 100 $\mu W/cm^2$) on E.coli cells was conducted with and without adding EtBr in the medium in concentration of 1 μg/ml. The results were registered by the method of anomalous viscosity time dependencies (AVTD). The obtained data have shown, that for cells with EtBr there is a tendency to change the sign of effective polarisation.

Introduction.

The experimental researches carried out in our laboratory for ten years have revealed the following regularities of the influence of the low-intensity millimetre radiation on the change in the genome conformational state (GCS) of E.coli cells and rat thymocytes (1-13):

1.4 Resonance frequency dependence of MM action on the GCS (1-13);

2.4 Decrease in the half-width of resonance at diminution of the magnitude of the power density of MMW (11,12);

3.4 Existence of selective rules of selection on circularly polarisation of MMW (3-5,7,8).

It was established, that the right and the left-handed polarised waves have different effectiveness at different resonance frequencies. In particular, at the

action on E.coli cells at 41.32 GHz, the right polarisation, and at 51.76 GHz - left-hand polarisation (3,5,7) was effective. The relative efficiency of the circularly polarised component of EMF had the dose dependence of the radiation of X-rays, applied to cells. It was shown, that the effect of left-and right-handed EMF became the same at 50 cGy. To explain this fact it was suggested, that the selectivity of biological effects of polarised MMW is connected with the DNA helicity, which is basically determined by right B-form, and by the availability of negative supercoils in the blast organisation of the chromatin. It is supposed, that only a minor part of DNA in cells (about 1 %) can be in the form of a left-hand spiral (Z-form). It should be noted that supercoiling of the chromatin (DNA-protein complex) exerts a substantial influence on the course of such elementary genetic processes as transcription, replication, recombination and reparation. In general, the regulation of supercoiling in a cell is the responsibility of enzymes of DNA topoisomerases. The density of topological coils can be changed under the action of a series of intercalators, one of which is ethidium bromide (EtBr). The embedding of EtBr between the foundations of DNA reduces in a modification of a secondary structure and relaxation of negative supercoils of DNA. The positive supercoiling arises at excess of the defined concentration of EtBr.

If the effective polarisation MMW is determined by helicity DNA-molecule (supercoils), the embedding EtBr in DNA can result in the change of the sign of effective polarisation of MMB. Proceeding from this hypothesis, we investigated the combined action of polarised MMW of one of the resonance frequencies (51.76 GHz) and EtBr on E.coli cells AB1157.

Materials and methods

The E. Coli K12 cells of AB1157 strain: F-thr-I ara-14 leu-B6 proA2 lacGI tsx-33 supE44 galK2 hisG4 rfbD Imgl-51 rpsL31 xyl-5 mtl-I argE3 thi-I l-rac- were used in this work. The E.coli cultures were kept in spreading on the Hottinger nutrient agar at 4^0C during 1-14 days. The cell were cultivated in the Luria broth base, Miller (tryptone "Sigma" 10 g/l, yeast extract "Sigma" 5 g/l, NaCl 10 g/l) at 33^0C without shaking. The bacterial culture reached an optical density of OD_{550} = 0.95-1.05 during 18-20 h of cultivation, which corresponded to the early stationary phase of bacterial growth. Then the cells were harvested by centrifuging and diluted in the M9 buffer (3 g/l KH_2PO_4, 0.2 g/l NH_4Cl, 6 g/l Na_2HPO_4, 1 g/l $MgSO_4$, 0.5 g/l NaCl, pH 7.0) with and without ethidium bromide (EtBr) to a concentration of $4*10^7$ cells/ml. In the work by B. Lambert and J.-B. Le Pecq (1984) it was shown, that the concentration of EtBr in E.coli cells of AB1157 will not increase with its increase in the buffer M9 from 1 μg/ml up to 10 μg/ml (cell concentration - $4*10^8$ cells/ml). Taking into consideration, that only 30-40 % EtBr

contacts with DNA, the remaining fraction contacts RNA, we obtain, that to one mole of the nucleotide of DNA is connected on the average up to 0.03 mole of the intercalator. The concentration of EtBr in the buffer M9 was 1 μg/ml. At this concentration of EtBr the conformation of the chromatin essentially did not vary (12). The suspension of cells with or without EtBr was distributed into 5 cm Petri dishes, 3.5 ml in each. Our device for MMW exposure of the cell to left-handed polarised (LP) and right-handed polarised (RP) EMR was described previously (3-8). A backward wave oscillator G4-141 was used for exposure. The irradiation device could simultaneously irradiate two Petri dishes with EMR of one frequency but different polarisations: left-handed circular and right-handed circular. The cells were exposed at a frequency of 51.760 ± 0.001 GHz and an average power density (PD) of 100 ± 10 μW/cm^2. The voltage standing wave ratio in the waveguide system was measured by means of a measuring instrument R1-39 with a voltage ratio meter V8-7 and did not exceed 1.4 in different points of the waveguide system. The ellipticity coefficient along the propagation axis of circularly polarised EMF was 1.02. In each experiment, a sham exposure was carried out while the oscillator was working at the resonance frequency and while the MMW radiation was maximally attenuated by means of output level of the oscillator and four metallic flap attenuators down to PD < 10^{-21} W/cm^2 (12). No reliable differences between the sham-exposure and control were noticed in all the conducted experiments.

In work (14) it was shown, that the kinetics of embedding of EtBr (at the concentration of 1 μg/ml in the buffer M9) in E.coli cells had a plateau beginning from 2 min after the adding of EtBr to the cell suspension. In our experiments the incubation of cells after dilution was not less than 30 min. The cells were exposed in Petri dishes for 10 min and incubated for 40-150 min. before lysis. The Petri dishes were shielded by a metal screen during simultaneous exposure to millimetre waves of different polarisation. During incubations the cells were shielded from the background MMW radiation and from the sunrays, which could lead to photochemical reactions of EtBr, with the aid of aluminium shields. We controlled the static magnetic field by means of a magnetometer TM 75-41. This field was 40 ± 5 μT in the places of exposure and incubation of cells.

The cells were lysed as previously described (1-12). The cell suspension was distributed from the Petri dishes to the polyallomer test-tubes, 1 ml in each. Solutions of lysozyme ("Sigma", 1.5 mg/ml) - 0.3 ml, sarcosyl (" Serva ", 2 %) - 1 ml and papain-glycerol ("Merck", 3 mg/ml - 10 %) - 0.7 ml were added in every 10-15 min. to each test-tube. All the solutions were prepared in a lysing buffer (0.25 M Na_2EDTA, 0.01 M Tris-base, pH 7.15). The lysates were kept in the darkness for 40-45 h, at 33^{0}C. The anomalous viscosity time dependencies

(AVTDs) were measured by means of an AVTD-analyser at a shear rate of 5.8 s^{-1} and a shear stress of 0.0065 N/m^2 as described previously. Maximum relative viscosity was calculated from AVTD-curves. Each version of the experiment included three measurements in different test-tubes which were compared with the corresponding variants of control or sham exposed cells by using the Student's t-test and paired t-test.

Results.

Irradiated and not irradiated cells were lysed at different stages of the incubation of cells during 120 mines after an exposure. As no significant differences between the values of AVTD-peaks in monitoring were revealed, all the results were normalised on integrated monitoring. No significant differences between the controls with and without EtBr were registered. The outcomes of 4 independent experiments are shown in Fig.1 and Fig. 2.

From figures 1 and 2 it is seen, that the adding of EtBr changed the sign of effective polarisation. Using the Student's t-test we conducted the paired comparison of the effectiveness of two circular polarisations for each temporal point of the development of the effect. No significant differences at separate temporal points were observed for cells with the presence of EtBr. However, the paired t-test has shown a greater effectiveness of right polarisation with a significance level of 0.0004. The coefficient of the correlation between the values of effects of right and left-handed polarisation was +0.98 with a significance level of 0.02. For cells without EtBr the effectiveness of the left-hand polarisation as compared with right was 1.14 + 0.06 at times of the order of 90 min. (significance level 0.02), while at 120 min. it reached the value of 1.28 + 0.06 (significance level 0.00002). The comparison of the effectiveness of the influence of right polarisation on cells with and without EtBr has shown significant differences at 40 min. ($p = 0.03$), 90 min. ($p = 0.04$) and insignificant for 120 min. ($p = 0.11$) by the Student's t-test. The application of the paired t-test has revealed the difference with the significance level of 0.02.

Discussion.

The researches (1-13), conducted in our laboratory, have shown, that the response of E.coli cells to the action of low intensity MMW has a systemic character and includes the modification in: change of the genome conformational state, cell division, gene expression, RNA and DNA synthesis. The modifications, induced by MMW, depend on, essentially, the time during and after the action. At short times of the action used in our experiments, the effects were observed within

1-3 hours after exposure. The recent researches have allowed to assume, that DNA of a cell is the basic target of MMW action:

1.4 The dependence of the resonance frequency of MMW from the haploid genome length of E.coli cells was established. The haploid genome length varied with the help of the insertion in bacterial chromosome of prophage λ (strain N99(λ)) and prophage λimm^{434}bio10 (strain N99(λ, λimm^{434}bio10)). The decrease of the resonant frequency was proportionate to the increase of the haploid genome length(6). These data have indicated the connection of the resonance frequencies with the genome structure and have been explained at reviewing the high-frequency oscillation in the DNA molecule (6,12,13).

2.4 Inversion of the sign of the effective polarisation MMW was detected after a preliminary action on cells by X-ray radiation. The effect of the inversion was observed in a wide range staring from the 0.5 Gy dose. It was estimated, that this dose induced about one single-strand DNA break per genome of the bacterial cell, reducing the relaxation of supercoiling DNA domains(4). DNA is the unique target, which can change the conformation at such low doses of exposure.

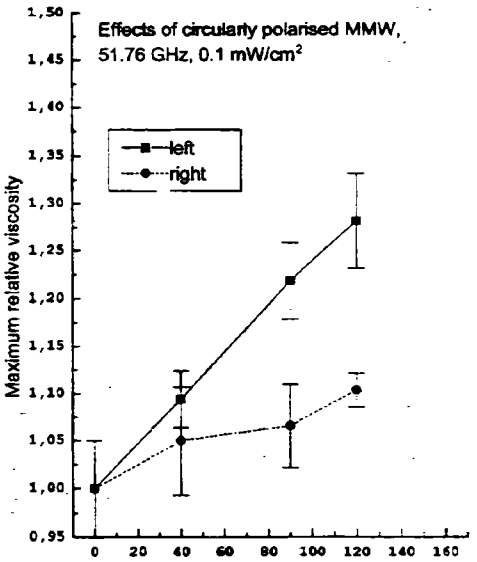

Fig.1 The time between exposure and lysis, min.

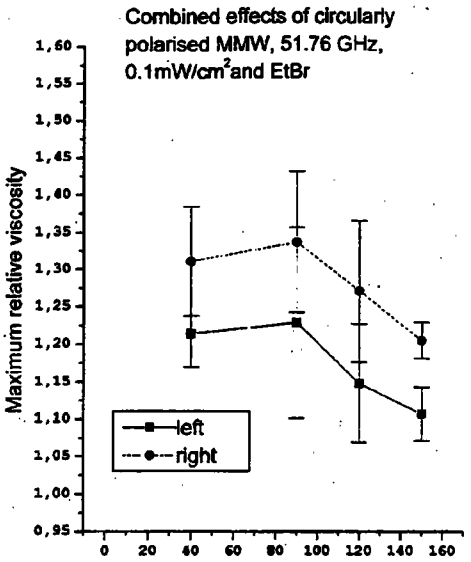

Fig.2 The time between exposure and lysis, min.

The established inversion of the sign of the effective polarisation at the action on cells of EtBr is one more fact for the benefit of the hypothesis, that DNA or DNA-protein complexes (chromatin) are one of the basic targets of MMW action on cells. Apparently, the sign of the effective polarisation is determined by the chromatin structure, namely the secondary form of DNA (B -, Z-form) and the sign of supercoiling of separate chromatin domains, which set a spatially - twisted distribution of an electronic density, ensuring the selectivity of absorption of polarised waves (12,13). In conclusion we would like to point out one more interesting fact: in the research of the action spectrum of MMW on E.coli cells a series of effective frequencies was obtained, which can be divided into two subgroups, distinguished from each other by the sign of the effective polarisation (12). This regularity points to the fact, that the target is the structure with an expressed character of asymmetry. Such a structure can be supercoiling chromatin of cells, whose basis is DNA. The majority of DNA sequences in alive cells is in B - form (right spiral). Some sites, with a primary content of G-Z nucleotides, are capable of forming the Z-structure DNA (left-hand spiral). It leads to the assumption, that DNA is the not the only target which can explain the asymmetry of the interaction of MMW with cells, however, as of today, there are no convincing data that other intercellular structures are capable of changing their helicity, as it has been established for DNA and the supercoiling domains.

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EXPERIMENTAL STUDY OF COMBINED EFFECTS OF NOISE AND ELECTROMAGNETIC FIELDS (EMF) ON ANIMALS

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As an enormous number of industrial enterprises, vehicles, high voltage power lines and power substations are found in any confined residential area; this may admittedly impose an adverse condition on humans in production, in the place of residence and in the environment in general. It is necessary, therefore, to do one's best to make an overall evaluation of possible adverse health effects from EMF exposure and to take purposeful action to prevent them.

Hence, the present study on the combined effects of noise and commercial frequency (CF) EMF is a timely one, in view of the constant growth of the amount of traffic and the density of power transmission lines within cities.

Within city limits, 25-40% of the population live in a state of permanent acoustic discomfort. The percentage of complaints of the traffic noise makes up 60—80% of the overall city noise complaints. The equivalent sound levels in city streets are as high as 65-80 dBA.

The basic sources of EMF are power stations and power transmission lines. The possible adverse effect of EMF has, until recently, been considered only in terms of its electrical component. The adverse effect of the magnetic component has not been taken into account.

However, recently a number of researches have been carried out (Wertheimer H., Leeper E. 1979, Milham S. 1982). The results point to a probability of cancer development under the effect of EMF.

The EMF and noise are wide-spread in the environment. To study their combined effect is important.

The purpose of our work was to study the combined effect of noise and extremely low frequency electromagnetic fields (EMF, 50 Hz) on the animals in experimental conditions.

The source of CF EMF was a high voltage power line (110 kV). The source of noise was a highway passing near the high voltage power line.

The studies were conducted on 40 white male rats (initial weight 170-190 gr). Three groups of the animals were formed: one control and two experimental ones. They were exposed to EMF of various levels and to noise of average and high levels. The levels of the electric and magnetic components of EMF and the noise were controlled during the whole period of exposure by devices HI-3604 (USA) and 2218 (Denmark).

Thus, in the area where the control group rats were placed (1) the intensity of the electrical field (E) was 1-2,5 V/m, magnetic induction (B) - 10-12 nT, equivalent sound level (L_{eq}) - 42-44 dBA, and maximum sound level (L_{max}) - 49-52 dBA.

In the second group area (2) the levels of EMF were 380- 450 V/m, H - 320-450 nT and noise levels were L_{eq} - 52-54 dBA, L_{max} - 65-68 dBA.

In the third group area (3) the levels of EMF were: E-350-460 V/m, H - 120-140 nT, and noise levels: L_{eq} - 62-65 dBA, L_{max} -83-89 dBA.

The second group animals were exposed to high levels of magnetic induction and average noise levels, while those in the third group - to low levels of magnetic induction and high levels of noise. The intensity of the electric field was practically identical in both groups.

Such levels of EMF and noise are typical for the environment in cities and residential buildings located near high voltage power lines and thoroughfares.

We carried out 10 such tests, four hours long each. The tests were conducted 21 hour after the exposure. i.e. on the following day after the end of exposure.

The activity of membrane-binding enzymes in tricarboxylic acid cycle (TAC) (pyruvate dehydrogenase, isocitrate dehydrogenase, 2-oxyglutarate dehydrogenase, succinate dehydrogenase) in the mitochondrions of the host brain and liver was researched. All manipulations were carried out in cold chamber NKR-17 at 2-3° C. The mitochondrial fraction was isolated from 10 % homogenate of the brain and liver by centrifugation.

The activity of dehydrogenases was determined by speed transformation 2,3,5 – triphenyltetrasolium chloride, in the presence of phenazinmetasulfate, into phormazan. The activity of enzymes was presented in μg phormazan on mg protein. It was determined by Louri method.

The level of glucocorticoids (11-OKS) was determined in blood plasma by fluorometry. As standard we used the corticosterone produced by Sigma (USA).

The ultrastructure of thymus and spleen cells was studied (rats in the control and experimental groups).

As a result it was determined that the combined effect of EMF and noise can lead to various changes in the body of animals. The compound effect of these factors on the animal body changes can be increased or reduced depending on the level and duration of each factor.

Thus, the combined effect of EMF with high level magnetic induction and noise of average level (group 2) leads to a decrease in the speed of dehydration in TAC mitochondrions of the host brain and liver in comparison with the control group.

The depression of pyruvate dehydrogenase activity by 24% and 22%, isocitrate dehydrogenase by 18% and 10%, 2-oxyglutarate dehydrogenase by 28% and 16%, succinate dehydrogenase by 18 and 16 % was detected.

The statistical differences were reliable ($P < 0.05$) for pyruvate dehydrogenase, 2-oxyglutarate dehydrogenase brain mitochondrions and pyruvate dehydrogenase liver mitochondrions only.

This depression in the tricarboxylic acid cycle may be connected with changing the normal state of the mitochondrial membrane (swelling, matrix clarification) caused by the action of EMF (Cholodov U.A. 1982, Cholodov U.A., Berlin U.V. 1984, Cholodov U.A., Shishlo M.A. 1979). The above results in the disruption the transportation of electrons and thus in the inhibition of dehydration processes in the tricarboxilic acid cycle

However, the combined action of EMF with low level magnetic induction and high levels noise (group 3) leads to an increase in the speed of dehydration processes in the tricarboxylic acid cycle of mitochondrions of the host brain and liver in comparison with the control group animals.

We detected an increase in pyruvate dehydrogenase activity by 12 % and 13%, isocitrate dehydrogenase by 24 % and 33 %, 2-oxyglutarate dehydrogenase by 15 % and 12 %, succinate dehydrogenase by 10 % and 12 % accordingly.

Table 1

Change of the brain TAC enzyme activity in rats after exposure to EMF and noise (μg of phormasan/mg of albumin)

##	Experiment series	pyruvate dehydrogenase	isocitrate dehydrogenase	2-oxyglutarate dehydrogenase	Succinate dehydro-genase
1.	Control (M ± m)	26.5 ± 2.13	6.2 ± 0.48	15.6 ± 1.19	23.4 ± 2.06
2.	CF EMF + medium- level noise (M ± m)	20.1 ± 1.17*	5.1 ± 0.53	11.2 ± 0.97*	19.2 ± 1.96
3.	CF EMF + high-level noise (M ± m)	29.8 ± 2.19	7.7 ± 0.63	17.9 ± 1.28	25.8 ± 2.34
	Δ(2 - 1)%	- 24.1	-17.7	- 28.2	-17.9
	Δ(3 - 1)%	+ 12.4	+ 24.2	+ 14.7	+ 10.2

* - differences are reliable $p<0.05$.

Table 2

Change of the liver TAC enzyme activity in rats after exposure to EMF and noise (μg of phormasan/mg of albumin)

##	Experiment series	Pyruvate dehydrogenase	isocitrate dehydrogenase	2-oxyglutarate dehydrogenase	Succinate dehydro-genase
1.	Control (M ± m)	8.7 ± 0.64	5.2 ± 0.46	21.3 ± 1.78	22.6 ± 2.04
2.	CF EMF + medium- level noise (M ± m)	6.8 ± 0.59*	4.7 ± 0.38	17.9 ± 1.43	18.9 ± 1.73
3.	CF EMF + high-level noise (M ± m)	9.8 ± 0.81	6.9 ± 0.71	23.8 ± 2.21	25.3 ± 1.98
	Δ(2 - 1)%	- 21.8	- 9.6	- 15.9	- 16.4
	Δ(3 - 1)%	+ 12.6	+ 32.6	+ 11.7	+ 11.9

* — differences are reliable $p<0.05$.

Table 3

Change of the 11-oxycorticosteroid level in blood plasma of rats after exposure to EMF and noise

##	Experiment series	11-oxycorticosteroids, μg/%
1.	Control (M+m)	25.3 ± 3.3
2.	CF EMF + medium-level noise (M+m)	32.7 ± 4.5
3.	CF EMF + high-level noise (M+m)	33.3 ± 4.3
	Δ(2 - 1) %	+29.2
	Δ(3 - 2)%	+31.6

These effects may by explained by the activation of enzyme systems due to a reduction of the biological effect of varying noise on animals. This effect depends on the increase in the duration of pauses and in the dynamic range of the noise (45 – 89 dBA), typical for traffic flows (Suvorov G.A., Shcarinov L.N., Denisov Z.I. 1984, Oleshcevitch L.A., 1985).

The study of reaction of the glucocorticoid function of adrenals has shown that the effect of EMF and noise leads to an increase in the functional activity of adrenals in the 2-nd and 3-d groups as compared with the control group.

In the 2-nd group the level of 11-oxycorticosteroids in blood plasma increased by 29.2 % and by 31.6 % in the 3-rd group as compared with the control group animals.

The study of the ultrastructure of thymus and spleen cells of the rats after exposure to CF EMF and noise has demonstrated that changes in the spleen were more appreciable than in the thymus.

Thus the common effect of various level EMF and noise on the lymphoid organs of rats consists in the accumulation of lymphocytes with pyknotic nuclei and also of tissue basophils with degranulation. The changes detected are transitory.

Thus, the results obtained make it possible to draw the following significant conclusions:

- The environmental physical factors (noise +EMF) can cause various changes in the organs and systems of animal.
- The combined effect of high level magnetic induction of EMF and average level noise depresses enzyme activity of the tricarboxilic acid cycle in the host brain and liver mitochondrion of rats.
- The effect of low level magnetic induction EMF and high level noise leads to increasing the speed of dehydration processes in the tricarboxilic acid cycle mitochondrion of the host brain and liver of rats.
- The effect of EMF and noise is accompanied by cell transformations in the lymphoid tissue (thymus and spleen) of rats. The common changes in the thymus and spleen are the appearance of tissue basophils with degranulation and of lymphocytes with pyknosis signs.

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STUDY OF COMMERCIAL FREQUENCY ELECTROMAGNETIC FIELD EFFECTS ON HUMAN HEALTH AND THEIR HYGIENIC RATING CRITERIA.

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Introduction

Principal sources of occupational exposure to commercial frequency (CF) electromagnetic fields (EMF) are outdoor switchgears of high- (HV), super-high- (SHV) and ultra-high-voltage (UHV) substations and overhead transmission lines (TL). The staff operating this equipment is an adequate model for the study of CF EMF influence on human health, as they are systematically and most heavily exposed to this factor.

Until recently, possible unfavourable health-related effects of CF EMF have been considered only in terms of their electrical component which is subject to the Russian hygienic regulations covering both occupational and general population exposure. The probability of unfavourable health effects of the magnetic component has practically been ignored.

A systematic study of the health status of those occupationally exposed to CF EMF was begun in Russia as far back as 1960s, when medical examinations of the staff servicing 220, 330, 400 and 500 kV substations were conducted (Asanova et al., 1963; Sazonova, Morozov, 1969; Dumansky et al., 1977 et al). Those investigations performed by specialists of Kharkov Institute of Occupational Hygiene, Kiev Institute of General and Municipal Hygiene and LIOT Institute revealed a number of unfavourable changes in the health status of the personnel. Those operating 400 and 500 kV substations had neurological complaints (headache, inertia, greater fatigue, and sleepiness) and also complained of disorders of cardiovascular and gastrointestinal systems. Such complaints were accompanied by functional disorders of nervous and cardiovascular systems in the form of vegetative dysfunction, tendency to tachycardia and bradycardia, arterial hypertension or hypotension. Longer visuomotor reaction time, higher olfactory sensitivity threshold, poorer memory and diminished attention, as well as reduced pulse frequency were also reported. Peripheral blood changes were expressed through moderate thrombopoenia, neutrophilic leukocytosis, lymphocytosis and monocytosis, tendency towards reticulopoenia, reduction of Hb and erythrocyte

counts, lower erythrocyte sedimentation rate (Abramovich-Poliakov, 1973). Similar data were obtained in a volunteers study (Dyshlovoy, Kachura, 1977). However, those investigations did not attempt to analyse the dependence of the above health status deviations on the CF EMF parameters in terms of their intensity and duration. Control over the electric component levels was exercised in a few single cases only, while the magnetic component was not measured at all.

The first Russian publications gave an impetus to the conduct of a number of similar studies in the USA, Canada, Spain, France, etc. However, their findings were mostly inconsistent with those of the Soviet researchers, as no significant heath status changes were revealed in people engaged in similar jobs.

Nevertheless, in later investigations performed in Russia it was revealed that the staff servicing 500 and 750 kV substations also showed changes in the functional state of their cardiovascular, nervous and immune systems, which, although not exceeding the norm, were sufficiently stable in character (Bezdolnaja, 1990; Rubtsova, Kosova, 1992; Zuev et al., 1996). Also reported were shifts in the cardio-respiratory system (Zaslavets et al., 1996), subjective evaluation of the staff's health status in the form of asteno-neurotic complaints, an upward trend of morbidity resulting in temporary disability (Talalaev, 1996) and of downward trend in the level of psychological adaptation reserves (Grabsky, 1996).

The inconsistency of the findings on the health status of those occupationally exposed to CF EMF is probably related to a relatively low voltage (< 400 kV) used at such facilities abroad, which implies weaker electric fields (EF) at work and different modes of their action and, in part, insufficient resolution of the investigation techniques used. Of special significance is the contribution of the EMF magnetic component to the changes observed, especially so in view of the latest evidence of their probable cancerogenic effect as reported in the world scientific publications.

Proceeding from the above, a comprehensive study was conducted which included an adequate hygienic assessment of human EMF exposures (with both components considered) as well as search for and development of the most adequate techniques making it possible to detect both initial forms of unfavourable changes in the health status and distant consequences of the action of this factor.

Scope and methods of investigation.

While studying the labour conditions the principle attention was paid to a hygienic assessment of CF EMF at work places of different groups working at 14

facilities (ultrahigh (500, 750 and 1150 kV) voltage substations and overhead power TLs). Both CF EMF components (electric and magnetic) were evaluated in parallel. While analysing the results of over 8500 measurements, the intensity and duration characteristics of CF electric and magnetic fields (MF) exposure on different job groups were determined. For this purpose the conditional dosimetry technique was used: average weighted values of the electric (E) and magnetic (H) component intensities at ground-level work places of switchgear staff and within high voltage (500, 750 and 1150 kV) line routes were calculated. The average weighted values were then recalculated to conditional exposure loads - per shift and per year with account taken of the number of workshifts per year for every job group. The data obtained were recalculated to conditionally averaged hourly load for each group. The calculations were made according to the following formula:

$$\frac{\text{E/H (kV/m / A/m; average weighted) x T (h/work shift) x N (work shifts per year)}}{\text{365 days x 24 h}}$$

The calculation results were compared: for the electrical component - with the similarly calculated standard permissible values of EF; for the magnetic component - with the standards (if available), or the international literature data on unfavourable CF MF influence of certain intensity parameters. It should be noted that this kind of evaluation makes it possible to determine exposure loads not only for different categories of those occupationally exposed to CF EMF, but also for general population subject to such exposure, without using individual dosimeters.

On the basis of data obtained, gradation of job groups was made depending on electromagnetic loads received at work while operating switchgear and TLs, which was later taken into account during medical, physiological and epidemiological investigations. Five groups were formed: I - linemen (maintenance crews of SHV TLs); II - substation repair teams; III - staff of relay protection & and automation gear service; IV - substation control room staff; V - communication, personnel of substation lightning protection and insulation, and other auxiliary services.

Evaluation of the health and functional status of those under examination (349 persons) was made on the basis of the data of clinical examinations performed by a therapeutist, a neuropathologist, an ophtalmologist and otolaringologist; of a detailed analysis of the cardiovascular and nervous systems; of determination of the status of the immune system and peripheral blood parameters.

An epidemiological cohort study of mortality of the staff servicing SHV power network facilities was executed by the retrospective cohort method. The study was conducted on the database of the study cohort made up from the subjects who had been exposed to CF EMF for not less than 1 year (1532 persons, 1319 of whom are alive, 141 had died and 72 outcomes remained unknown). The total number was 19272 person-years of observation for males and 4519 - for females. 3 groups were formed: I - substation repair workers and linemen (group I and II of the functional medical research); II - relay protection and insulation workers and operators of substations (group III and IV of the clinical physiological study); III - all remaining staff who are practically not exposed to CF EMF. To establish a connection between the CF EMF effect and deaths from different causes, a standardised mortality risk ratio for certain nosological forms, differentiated for sex and the selected criterion, was determined.

Results

An analysis of the electromagnetic situation in the workplaces of 500, 750 and 1150 kV outdoor switchgear testifies to a similar character of distribution of both components of CF EMF. The average weighted values of the measured values of E and H levels are, accordingly:

For 500 kV substations - 9,6 kV/m and 3,40 A/m;
750 kV - 10,4 kV/m and 3,68 A/m;
1150 kV - 12,0 kV/m and 3,66 A/m.

Along TL routes the typical average weighted EF levels were: for 500 kV TL - 7,7 kV/m; 750 kV TL - 10,0 kV/m; 1150 kV - 9,8 kV/m. For the MF component the average weighted values, (at loads equal to 10-30 % of the nominal value) were: for 500 kV TL - 3,7 A/m; 750 kV TL - 3,5 A/m; 1150 kV TL - 4,0 A/m.

The calculations of exposure loads, performed with due account taken of the work- time evaluation data, show that the greatest degree of EMF exposure was experienced by group I (1,1-1,4 kV/m and 0,5 A/m per hour within a year). Besides, during TL live-line maintenance the linemen are subjected to periodic short-term EF and MF influence with levels up to 2000 kV/m and 6 kA/m, and to the factors related to TL corona discharge: air-ions, broadband range radiofrequency EMF, nitrogen oxides. The availability of screening clothes largely ensures the workers' protection from CF EF, radiofrequency EMF, air-ions and capacitive currents, but not from CF MF.

The comparison of the exposure values obtained to the results of similar calculations for EF standard values shows, that for 2 groups of staff (linemen and repair personnel), the averaged hourly exposure load to the electric component only to an extremely insignificant extent (10-20 %) exceeds the corresponding 50 Hz EF MPLs for occupational exposure, and for the magnetic component it is 1,5-2 times higher than the values given in a number of foreign research publications, where they are regarded factors increasing the leukaemia and brain cancer risks. In two other chosen groups the exposure loads, were respectively 2 to 4 times lower, while the substation auxiliary workers' group is practically not exposed to CF EMF. This made it possible to consider them as a conditional control group.

The study of the body functional state of workers exposed to CF EMF with different exposure loads, has revealed, in the subjects exposed to the greatest EMF loads, a greater incidence of pathologies of the cardiovascular and nervous systems, and in the absence of a pathology - overstepping the bounds of standard indicators of general and regional blood flow parameters, typical for the development of circulatory system dystonia according the hypertensive type, adaptive changes in the nervous system and shifts of peripheral blood and immunological parameters (increase of monocyte counts, violation of a immunoregulatory cells parity, tendency to a reduction of eosinophile counts, and in group I - eosinophilia, tendency to the depression of the humoral part of immunity), indicating both the adaptive-compensatory character of the processes, and the risk of failure of these processes. The data obtained provided justification for including the subjects of groups I and II in the risk group on the basis of their blood and immune systems parameters. In the group of conditional control the average values of most parameters under evaluation did not display any significant deviations from the norm.

Dynamic (during 6 years) observations of group I, divided into two subgroups depending on whether they performed live-line maintenance or not, have revealed towards the end of the observations a minor tendency to an increase in the incidence of vegetative dysfunction of the hypertensive type and of neurological symptoms, appearing to a greater degree in the subgroup not involved with live-line maintenance. This testifies to a minor influence of the occupational factors acting near TLs on the workers' health status, apparently as a result of the sufficient protection provided by their screening clothes.

On the whole, the data of the medical and physiological study testifies to the presence of significant modifications of the body functional state of those exposed to CF EMF, when the electrical component exposure loads are close to, or insignificantly exceed, the MPLs, while the magnetic loads are commensurate with

the levels mentioned in publications and indicative of the risks of leukaemia and brain cancer. It does not preclude the probability of a further increase of pathology and observable functional disorders in the subjects occupationally exposed to CF EMF, and, proceeding from the hypothesis of their promotor effects, and the possibility of failure of adaptive mechanisms with further increase of total exposure loads.

The research of the mortality levels of the staff exposed to CF EMF has shown, that the indicator of the standardised relative mortality risk ratio (SRR) from all causes was, for the cohort as a whole, 0.59 (confidence interval 0.5-0.7), including SRR=0,61 (confidence interval 0,51-0,72) for males; and SRR = 0.39 (confidence interval 0.17-0.78) for females, reflecting the phenomenon called "the healthy worker effect".

The structure of the death causes reflects a picture appropriate to present-day Russia. The first place is taken by cardiovascular system diseases (32,2 % males and 50,0 % females). The second place in males - malignant tumours (30,1 %), third - accidents, traumas and poisonings (24,8 %). The number of females in the cohort was too small, thus it proved impossible to completely evaluate the structure of their death causes.

Estimates of SRR has revealed no increase in the death risks from any of the following causes: diseases of the blood circulation system (SRR=0,53; confidence interval 0,39-0,70), all forms of cancer (SRR=0,80; confidence interval 0,57-1,09), accidents, traumas and poisonings (SRR=0,67; confidence interval 0,46-0,93), suicides (SRR=0,45; confidence interval 0,16-0,98). At the same time the increase in male leukaemia risks - 2,03 (confidence interval 0,23-7,31) is statistically insignificant, with the SRR=2,39 (confidence interval 0,03-13,31) in group I; and in group II - SRR= 2,86 (confidence interval 0,04-15,71). In group III no deaths from leukaemia were reported. The increase in the SRR of death from brain cancer revealed in group I - 1,3 (confidence interval 0,64-3,7) is also statistically insignificant.

The data, obtained by us, coincide with those of most foreign researchers, and they can be considered as reflecting the tendency to an elevation of risks of development of certain malignant new growths in those occupationally exposed to CF EMF with the averaged loads of 0,3-0,5 and 1,1 kV/m (electrical component) and 0,1-0,2; 0,4-0,5 A/m – (magnetic component).

Conclusion

On the whole, the results of the above medical, physiological and epidemiological studies correlate among themselves and allow to assume the probability of unfavourable changes in the health status of humans occupationally exposed to CF EMF with the above-mentioned exposure loads to the factor and to consider the influence of these CF EMF levels as a risk factor.

Along with a minor excess of the electrical component loads, as compared with those equal to MPLs, on those most exposed to EMF, special attention must be paid to the fact, that the magnetic component exposure loads are much lower than the present-day MPLs both in Russia and most other countries. Therefore the problem of their contribution to the pathology and changes of the body functional state observed acquires special urgency. The data obtained confirm the necessity of an analysis of the contribution of the magnetic component to the observable modification of the body functional state and point to the urgency of revision of the hygienic rules.

MF levels acting on humans, if one proceeds from the generalised formula of dependence of induced current density (j) from the MF level (B/H) (Bernhardt, 1986; etc.), should not induce currents producing significant biological effects in humans. However, according to the data by Baraton et al. (1993), if one takes into account the presence of the three MF components on axes X, Y and Z and with the incident H=800 A/m, a 10 mA/m^2 current, which is commensurate with the threshold of sensitivity of nervous tissue, is induced in the body. At the same time the experimental data obtained by us, when extrapolated from animals to humans, have shown a possibility of influencing the functional state of the nervous and immune systems at the H levels of about 100 A/m, i.e. those inducing a current of about 1,1 mA/m^2. Thus, with the levels observed at workplaces, j values can reach 1 mA/m^2 and, by synergy, strengthen the EF component effects.

Apparently, it is the influence of the currents induced by both EMF components that causes the above-mentioned unfavourable health changes in those most exposed to EMF. The surface effects of EF, which can have a greater biological efficiency if acting through acupuncture points, in combination with the penetrating action of MF, can, by synergy, result in strengthening of unfavourable influence of CF EMF even at the levels found in workplaces. As a result, the health safety of the personnel in groups I and II groups cannot be completely safeguarded which calls for a revision of the hygienic rules. Our own data and their comparison with those available in the literature concerning the character of bioeffects

depending on the induced current density make it possible to develop new hygienic standards for CF MF occupational exposure.

Furthermore, starting from the premise that the induced currents both on the surface and inside the human body (due to the electrical and magnetic components action) influence the human electrogenic structures (and the effective value is their density (j)), in order to prevent the CF EMF unfavourable influence on humans organism we suggest that, for MPL substantiation, one should take into account both the EF and MF j values and that can be the basis for CF EMF hygienic standards. It seems to be most acceptable to use as MPL of each component the j value equal to 1 mA/m^2 (considering the undistorted EP levels corresponding to the Russian hygienic standard for the whole working day (5 kV/m) which corresponds to the exposure load of about 1 kV/m per hour, and to the magnetic H level of 80 A/m (100 μT), with an appropriate exposure load of about 9,4 A/m per hour for within one year). We suggest that the calculation should be made according to the following formula:

$$j = \sqrt{j^2(\text{due to E}) + j^2(\text{due to H})}$$

Hence the total j of both electrical and magnetic components should not exceed 1,4 mA/m^2. Such an approach allows one to implement the regulation of operational modes and exposure times for a work shift or for a whole work year depending on the EMF levels of both components. The suggested solution of the problem of the hygienic regulation of CF EMF occupational exposures involving both components has a preliminary character and requires clarification as more data are accumulated on the character of low-level CF EMF influence by virtue of probability of the information character of their effect. Nevertheless, the proposed principle of CF EMF regulation can be also used for developing MPLs of both CF EMF components for non-occupational effects as that problem is highly topical now.

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THE DOSE-POWER APPROACH IN HYGIENIC STANDARTIZATION OF MICROWAVES: THE CONCEPT, BIOPHYSICAL MODELING, EXPERIMENTAL ESTIMATION

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At present the difference in the hygienic standards for electromagnetic radiations of the microwave range in various countries may be as great as 10-100 times. First of all these distinctions are related to the absence of a general methodological approach to experimental and epidemiological research conducted with the aim of developing radiofrequency health criteria[3, 5, 8, 12-14].

The concept "of complete prevention of health risks" was based on the establishment of MPLs for prolonged action of electromagnetic fields (EMF) depending on the evaluation of the minimal microwave levels provoking a response from the most susceptible functional systems of the body, in particular the central nervous system. These intensities of EMF (about 10 $\mu W/cm^2$) were qualified as potentially dangerous for health. We agree with those researchers, who consider this approach to hygienic standardisation insufficiently correct, because the existence of biological responses to low level environmental factors is a normal phenomenon for the biosphere and humans and need not be accompanied by negative consequences [2, 6, 11].

In the opinion of other researchers, MPLs for microwaves should correspond to those absorbed doses, the excess of which results in the disturbance of physiological parameters of functional systems of biological objects which cannot be compensated. One can consider such an approach more adequate for the solution of the problem of standardisation and we suggest that it should be taken as a basis for further discussion. However, exposure limits (from 10 up to 100 mW/cm^2), obtained in this way, in our opinion, are significantly overestimated, since they do not take into account possible action of the additional factors, disturbing thermal homeostasis and, thus, are insufficient for the solution of the problem of health criteria.

Improvement of hygienic standardisation should be based on definitely reliable, stable criteria yielding to a strict quantitative estimation. The modern notions concerning the biological effects of low level microwaves do not deny the possibility of their specific action on biological structures. Nevertheless we consider that, for the problem of hygienic standardisation, more significant are

those EMF biological effects, which are caused by the absorbed electromagnetic energy accompanied by a remarkable heat dissipation in the bioobject. In this case the increase in the body temperature might not be instrumentally registrable. The possibility of a non-uniform distribution of the energy absorbed in biological tissue should first of all be taken into account as a specific effect in the process of hygienic standardisation. We consider it possible to use, for the purposes of determination of hygienic standards for microwaves, any strictly reproducible functional shift, caused by the disturbance of thermal homeostasis induced by EMF exposure. This makes it possible, on the basis of the available facts concerning the thermogenic EMF effects and as a result of modelling, to quantitatively predict the condition of the body thermal balance in comfortable or heavy heat exchange conditions, and also to give an extrapolated estimation of the level of professional risk according to the criterion of thermal effects of microwaves of different carrier frequency and intensity.

Such an approach to the problem of determination of safe levels of microwave irradiation can be called 'dose-power approach'. For its implementation it is first of all necessary to develop a mathematical model of microwave-induced thermogenesis in animals and humans, as well as to identify its parameters and to obtain of prognostic dose-temporary characteristics of EMF effects. An important condition for adequate modelling is the provision of a possibility of keeping account of the combined action of microwave exposure with other factors, capable of changing the body thermal homeostasis.

For calculating the general conditions for microwave heating of a body in the conditions of climatic comfort, one can use the following equation:

$$\Delta T = \frac{\gamma \cdot P}{\beta \cdot c}(1 - e^{-\beta \cdot t}), \qquad (1)$$

where ΔT - the increase of average body temperature, °C;
γ - the coefficient of the specific effective absorption cross-section, cm^2/g;
P - the power flux density of electromagnetic energy, mW/cm^2;
c - the specific thermal heat capacity, J/kg °C;
β - the coefficient of heat emission, s^{-1};
t - the exposure duration, s.

For conditions, other than comfortable, a quantitative evaluation of thermocompensation reaction is possible. It is known [1, 9, 10], that the change of body temperature is an integrated index of the activity of thermocompensation systems and factors, breaking the thermal balance (microwave irradiation, physical work, increased temperature and the humidity of the environment). Such integrative thermogenic action of microwaves and other factors can be described by the equation:

$$c\frac{d(\Delta T)}{d \cdot t} = W_1 + W_2 , \qquad (2)$$

where W_1 - the specific absorption rate, W/kg;
W_2 - the intensity of the heat content change, caused by the action of destabilising factors, W/kg

It is possible to take into account the influence of the environment (clothes thermoinsulation, the air movement velocity) on body heat content through the change of the coefficient of heat emission according to the expression:

$$\beta = \beta_0 \cdot R_0 / R , \qquad (3)$$

where β_0 - the coefficient of heat emission in comfortable conditions at thermoresistance (thermoinsulation) of clothes R = 0.5 clo, s^{-1};
R_0 - the thermoresistance in comfortable conditions, clo;
R - the thermoresistance of a body at a given air movement velocity and thermoinsulation clothes, clo.

At identification of the model parameters, the coefficient γ of specific effective absorption cross-section describing absorption of electromagnetic energy, was evaluated in special experiments in which the amount of energy absorbed by the animals of different weights during microwave irradiation was determined by the calorimetric method. It was shown in our investigation that the extrapolated values of γ (cm^2/g) for various bioobjects could be calculated by the following formula obtained empirically:

$$\gamma = 1/\sqrt[3]{m}, \qquad (4)$$

where m - the weight, g.

To forecast the thermogenic effect of microwave irradiation, we developed the method of establishing the coefficient of heat emission for living organisms, including humans. For the comfortable conditions the next formula was applied:

$$b_0 = M_0 / c \cdot \Delta T, \qquad (5)$$

where M_0 - the level of the basal metabolic thermoproduction, W/ kg;
c - the specific thermal heat capacity, J/kg °C;
ΔT- the temperature difference between the object investigated and the environment.

The presence of bioobjects in conditions, influencing the thermal balance of organisms, results in the change the coefficient of heat emission according to the formula:

$$\beta = \frac{\left[M_0 + W(t) - m \cdot c \cdot \Delta T(t)\right]}{M_o} \cdot \beta_0, \qquad (6)$$

where M_0 - the level of the basal metabolic thermoproduction, W/kg;
W (t) - the additional energy, produced in the organism by the action of the external factors, W/kg;
ΔT (t) - the increase of temperature during time (t) of exposure, ° C;
m - the body mass, kg;
c - the specific thermal heat capacity, J/kg °C.

The experimentally established values of γ for laboratory animals (7 GHz), as well as calculated γ-values for humans and forecast β-values for animals and humans are presented in Table 1. The calculations were performed using the equations presented above.

Table 1
The basic parameters of the model describing the microwave (7 GHz) heating of various bioobjects

Object	γ, cm^2/g	β, c^{-1}
mouse	0.36 - 0.42	$4.0 \cdot 10^{-4}$
rat	0.18 - 0.22	$1.8 \cdot 10^{-4}$
rabbit	0.07 - 0.08	$1.0 \cdot 10^{-4}$
dog	0.06	$6.0 \cdot 10^{-5}$
man	0.023	$2.5 \cdot 10^{-5}$

It is known that physical work, increased temperature of the environment and humidity can change the thermal condition of an organism. The intensity of the additional heat accumulation, caused by these factors (W_2), was calculated on the basis of the literature data [1, 4] according to the ratio:

$$W_2 = \Delta T_{\text{äð}} \cdot c / t, \qquad (7)$$

where ΔT - the increase of body temperature during staying in heavy environment conditions, °C;
t - the duration of experiment, s;
c - the specific thermal heat capacity, J/kg °C.

The values of W_2 for humans calculated by using the formula (7), depending on external temperature, relative air humidity and the level of physical load, are summarised in Table 2.

Table 2
Values of W_2 parameter for man in various environmental conditions

Temperature, °C	Humidity,%	The level of physical work	W_2, W/ kg
40	15	Middle working load, 300 W	0.25
40	15	Rest, easy work	0.17
40	45	- " -	0.46
50	45	- " -	2.41
40	85	- " -	2.54
50	85	- " -	4.50
35	45	Heavy physical work, 700 W	3.32

The proposed mathematical model of the thermogenic action of microwaves has two distinctive features. Firstly, it has been developed specifically for solving the problems of hygienic standardisation, therefore the identification of its parameters use was made of the data taking into account the most adverse exposure conditions for human thermoregulation. Secondly, the utilization in the model of the W_2 values for conditions other than comfortable makes it possible take into account the integral interrelation between the parameters of external environment, thermoinsulation of clothes, physical work and functioning of thermoregulation systems. Such an approach can improve the reliability of the forecast of MPL of radiation for real conditions of human activities.

For verification of the model we have used the experimental data published by others [1, 5-7] for the lethal effects of microwaves (2450 MHz) in experiments with dogs, assuming a death outcome after overheating a dog's body by 3.5 °C.

According to the equation 1, the exposure duration (t) for a subject to obtain a given temperature increase (ΔT) can be determined by the equation:

$$t = \frac{1}{\beta}\ln(1 - \frac{\beta \cdot c \cdot T}{\gamma \cdot P}). \qquad (8)$$

For calculations we assumed that $\gamma = 0.06$ cm^2/g, $\beta = 6 \cdot 10^{-5}$ c^{-1}. As can be seen from Table 3, the calculated duration of a dog's life under microwave irradiation (exposure time needed for 50% dog mortality - ET_{50}) corresponds well to the experimental data.

Table 3
The calculated and experimental data for the duration of a dog's life during microwave irradiation (2450 MHz)

Power Flux Density, mW/cm^2	ET_{50} Experimental (min)	ET_{50} Calculated (min)
100	5.82	6.6
300	11.4	11.1
500	39.0	35.0

We have also compared our calculated and experimental data, obtained for rats after combined action of microwave radiation (λ = 7 GHz) and physical working load (running track). The intensity of the heat accumulation W_2 after the running reached 3 W/kg for all the cases analysed. The results are presented in Table 4. One can see from this Table that the calculated thermogenic efficiency of microwaves fairly well coincides with the experimental data. At lower microwave intensities the predicted ΔT-values are greater than the experimental ones. It means the availability of some additional reserves of thermocompensation, which were not taken into account in the model considered and which can provide an additional reserve factor if this approach to standardisation is chosen.

We suggest that, for hygienic standardisation of EMF, one should take as a basis the principle of maintaining the isothermal state of the body without any additional demands on the thermocompensatory systems in the conditions of climatic comfort. In such case the SAR should not exceed the natural fluctuations of basal metabolism. It is known that this physiological parameter is rather stable for any biological species of homothermal animals. From man to man it varies not more than 10 %, i.e. by 0.13 - 0.14 W/kg. Under this condition, the maximum raise of body temperature, triggering the system of thermocompensation, reaches 0.2 -

0.25 °C. Our calculations show that EMF intensity, at which the heating of a body even with a long exposure in the conditions of comfort does not exceed this magnitude, and is equal to about of 5 mW/cm^2. Clothes, which hamper heat dissipation, raise the thermogenic effect of microwave radiation up to 25-30 %, while some reasonable increase of humidity and air temperature requires a decrease of the normative level of microwave irradiation approximately by half. At last, taking into account a possible non-uniform absorption of microwave energy, we arrive at a safety standard of about of 1 mW/cm^2.

Table 4

The calculated and experimental data for the temperature increase in rats for separate or combined use of microwave irradiation and physical working loads

Conditions of experiment	W_1, W/kg	W_2, W/kg	ΔT exper., °C	ΔT calcul., °C
Physical working load (PWL)	-	3	2	2
Microwaves (50 mW/cm^2)	9	-	2	2
Microwaves (50 mW/cm^2) + PWL	9	3	7.1	8
Microwaves (35 mW/cm^2) + PWL	6.3	3	5.1	6.2
Microwaves (25 mW/cm^2) + PWL	4.5	3	3.9	5.0
Microwaves (10 mW/cm^2) + PWL	1.8	3	2.0	3.2

It is important to emphasise that the approach presented here permits to predict dose-temporary safety limits of presence in relatively intensive electromagnetic fields with higher, but physiologically permissible, levels of additional body heating.

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Status Report on the IEEE Standards Coordinating Committee 28 (SCC-28: Subcommittee 4, Safety Levels with Respect to Human Exposure, 3 KHz to 300 GHz): Approach to Reviewing the Technical Merit of the Existing Literature Database: Implications and Benefits for Future Research

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Good day everyone. First, I would like to thank Dr. Youri Grigoriev and the members of the Organizing Committee for inviting me to participate and to speak to you today.

As I expect is the case for many of you, I have learned that it is very important in reading the literature to be able to understand enough about what procedures have been used in a given study to be able to have reasonable confidence that the conclusions reached by the authors are valid.

There are, of course, many reasons why essential information may not be in a paper. Often, an editor will say that you must shorten the length of a paper. Other times, it might accidentally be forgotten. The worst case would be if it were left out on purpose by the authors, but almost as important is that the information was left out simply because something was not measured or done in the experiment.

In any event, I believe that many of you will agree that detailed information is important, especially in a field such as bioelectromagnetics. In this field, the entire focus of a paper may be on differences between exposed and control (sham-irradiated) samples which are very small, sometimes as low as 5 - 10%.

In the process of setting standards, where there are important decisions to be made based on understanding biological effects and distinguishing between biological effects and known or possible adverse human health effects, the quality and technical merit of the papers available becomes very important.

Considering these issues, Standards Co-ordinating Committee 28 of IEEE, as part of its current round of review of the literature available in the radiofrequency radiation range of the electromagnetic energy spectrum, agreed to undertake a process of establishing or rating the technical merit of all of the relevant articles in the literature. While there are many reviews, letters, comments, and technical reports available, the initial focus of the review is on original articles. A Literature Surveillance Working Group was established to compile articles

which focus on Engineering/Dosimetry, Epidemiology, In Vitro Exposure studies, or In Vivo Exposure studies. The Literature Surveillance Working Group also includes in the lists of articles that it regularly updates any papers recommended by individuals or government agencies. Any interested party has the opportunity to recommend an article for review. Obviously, one shortcoming is the focus by the process on English language publications; that is one reason I am so pleased to be here speaking to you about this today. With this exception, the review approach was designed to eliminate any future challenge that individual or groups of papers were ignored.

The process which was established is based on nothing less that good scientific methodology. It is designed to have two (2) reviewers with expertise in Engineering and Dosimetry, and separately two reviewers with expertise in either In Vitro, In Vivo, or Epidemiology, review each paper. The separate reviews ultimately are to be sent on by the separate Working Group Chairs, who initially assigned the papers for review, to the Chairman of the Risk Assessment Working Group (RAWG). This person, and only this person, will therefore have access to the separate Engineering/Dosimetry, Biological Working Group, and (if requested) Statistical Working Group ratings. The Chairman of the RAWG will be able to access the information in the database on behalf of that Working Group, and the parent committee. This approach is designed to maintain security of the incomplete reviews, and subsequently the complete reviews. Decisions with regard to future access by the scientific community to the ratings have not yet been made.

One additional action of the reviewers, which I did not mention previously, is that when the reviewers give a low rating in one of the parts of the review, and/or a low overall rating (which is NOT an average value of the scores of the sections), they are asked to explain why the low rating is given. If the rating is made available and challenged in the future, this information will be useful.

Clearly, the literature review part of the Standards development process is not designed to make decisions about standards. It is designed to make the RAWG aware that a given article identified for consideration is of either adequate technical merit or better, and also to document, if an article is of poor quality, why the reviewers decided that it was of poor quality.

In order to make the process manageable, the U.S. Air Force agreed to sponsor the development of a computerized version of the literature review. This is designed to facilitate the process be minimizing the use of paper, and also to make access to the information in the database by the Chairman of the Risk Assessment Working Group both very easy and also very useful.

In summary then, the major goal is to provide to the members of the Risk Assessment Working Group (RAWG) of Subcommittee 4, SCC-28, many of whom will be unfamiliar with the techniques described in any given manuscript or report, a rating of the technical merit of each article. The rationale is that many published articles, on careful review by experts in the field, have been found to have major technical deficiencies.

One purpose of the computerization of the review process is to document in a readily accessible manor the technical merit of articles of interest. The rating process will take advantage of the knowledge of persons available today who are familiar with the techniques (exposure, dosimetry, biological effects, epidemiology, statistics) used in the published studies. Persons with this same knowledge may not always be available in the future.

A second purpose is to document the reviews in such a way that the RAWG can automatically search the database for articles dealing with any hazardous effect, or any biological effect, or any exposure parameter, using one or more of the data items entered by the reviewers in the fields in the screens used by the reviewers.

Still another purpose is to allow the RAWG to have access to the reviews of all of the original articles considered, so that the RAWG could take advantage of the contributions of authors in articles which might not be technically meritorious, but which would still be of intellectual value.

Inherent in the design of this process are some other related uses, and this again is why I was most interested in speaking to you today.

First, the process in effect provides a "quality-control" format for each investigator to consider, if they wish, before their research is even performed.

Secondly, the system provides editors, again if they choose, with a list of items that they can ask peer-reviewers to consider when manuscripts are submitted for publication. This could be very beneficial, since often available and willing reviewers do not have expertise in the diverse engineering and biological fields found in the radiofrequency radiation research field.

Finally, while I will not have enough time to show you all of the screens available, I have selected a few to show you. The review process is about half-way complete using paper forms; we are at this very time switching over to the computerized version. I hope that through the good offices of the U.S. Air Force,

the software will be made available at minimal cost for use by interested persons. I have made a paper copy of the screens available to Dr. Grigoriev, and I am hoping a way can be found to make copies available to those of you who are interested.

Again, I wish to thank Dr. Grigoriev and the organizing committee for the opportunity to speak to you today.

RUSSIAN HYGIENIC RULES FOR EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELD: PRESENT STATUS AND INTRODUCTION

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The hygienic rules establishing, with the purpose of health safety of workers and general population, maximum permissible levels (MPL) of extremely low frequency electromagnetic fields (EMF) in Russia mainly concern only the commercial frequency (CF) range of EMF.

CF EMF hygienic regulations are implemented separately for electrical (EF) and magnetic (MF) fields. The regulated EF parameter is the strength, which is evaluated in kilovolt per meter (kV/m), and for MF - magnetic induction or strength of a magnetic field, evaluated accordingly in milli- or microtesla (mT, μT) and ampere or kiloampere per meter (A/m, kA/m).

There are hygienic standards of CF EF and MF occupational exposure and CF EF standards for non-production effects in Russia now. CF MF permissible levels for general population have not been developed.

The development of hygienic standards in Russia is created on the basis of comprehensive hygienic, medical, physiological and experimental investigations (Savin, Nikonova, Morozov et al., 1979). Hygienic research serves the purpose of factor time-level parameters determination; medical and physiological studies are directed at the evaluation of health status and physiological functions of humans. The experimental research is carried out on animals with the purpose of detecting the threshold of harmful effects of the factor, and, with an additional factor of hygienic safety, serves, as a rule, as a basis for determination of standard values (permissible levels). In recent years, in the process of substantiation of permissible levels increased attention is given to the role of epidemiological studies.

Until recently only the electrical component of CF EMF was regulated. The first hygienic rules adopted in 1975, introduced the (strictest in the world) maximum permissible level (MPL) of 50 Hz for occupational exposure to EF, depending on duration. The principle of time-differentiated EF MPL was originally introduced in a stepped gradation, then an empirical formula, reflecting a ratio between EF strength and permissible work time for the intensity range from 5 to 20 kV/m, was used as a basis.

According to the standardisation documents regulating occupational exposure in Russia now in force, the permissible level for a complete working day is 5 kV/m, and the MPL for a 10 minute exposure is 25 kV/m. In the intensities interval (E) from 5 to 20 kV/m the permissible working time (T) is determined according to the formula T(h) = 50/E - 2. And fixed in the regulating documents, unlike the normative documents of most countries, is not only the EF MPL of 50 Hz, but also the methods and means of control, and a set of measures on workers' protection, implementing the principles of protection by time, protection by distance as well as protection by collective and individual protective means.

For the population at large only CF EF levels emitted from 330-1150 kV transmission lines (TL) are regulated now. The EF strength from TLs of lower classes of voltage is not regulated, though in the near future improvements involving non-industrial sources will be introduced in the CF EF hygienic regulations to extend the MPLs now in force to other EF sources including 110 and 220 kV TLs, as their EF levels inside residential areas are commensurate with the standard MPLs. Hygienic standards differ for different areas: from 0.5 kV/m inside residential buildings and 1.0 kV/m in residential areas up to 20 kV/m in remote areas. In populated areas, outside zones of residential buildings, the MPL is 5 kV/m; at intersections with roads of I-IV class - 10 kV/m and in the unpopulated areas - 15 kV/m.

Prevention of unfavourable CF EF effects on the population is ensured by, along with introducing differentiated MPLs depending on the type of territory (residential, frequently or rarely visited), establishing sanitary protection zones of various size for TLs of different classes of voltage, which provides protection for humans due to both the restriction of exposure time, and the implementation of the principle of protection by distance.

CF MF levels are now regulated only for occupational exposure. They were established considerably later and are differentiated for time, modes of interrupted exposure with different t and τ values. MPLs are from 1.4 up to 10 kA/m (table 1); one of the modes covers continuous 50 Hz MF exposure.

Apart from the indicated hygienic standards for conditions of live-line maintenance of extremely high voltage TLs, the following tentative safety levels are established: 4 mT (3.2 kA/m) - for conditions of whole body exposure, and 6.5 mT (5.2 kA/m) for conditions of local exposure of extremities (OBUV No 5060-89). The daily duration of work under these conditions should not exceed 50 % of the working day.

Table 1
MPLs for 50 Hz magnetic field occupational exposure

Work time, Hour	Magnetic field strength, A/m		
	Continuous and interrupted MF, with $\tau \geq 0.02$ s; $t \leq 2$ s	Interrupted MF, with $60 \text{ s} \geq \tau \geq 1$ s; $t > 2$ s	Interrupted MF, with $0.02 \text{ s} \leq \tau < 1$ s; $t > 2$ s
Up to 1,0 (Inclusively)	6 000	8 000	10 000
1.5	5 500	7 500	9 500
2.0	4 900	6 900	8 900
2.5	4 500	6 500	8 500
3.0	4 000	6 000	8 000
3.5	3 600	5 600	7 600
4.0	3 200	5 200	7 200
4.5	2 900	4 900	6 900
5.0	2 500	4 500	6 500
5.5	2 300	4 300	6 300
6.0	2 000	4 000	6 000
6.5	1 800	3 800	5 800
7.0	1 600	3 600	5 600
7.5	1 500	3 500	5 500
8.0	1 400	3 400	5 400

A recently conducted series of hygienic, medical, physiological, experimental and epidemiological investigations furnished justification for stricter MPLs of 50 Hz continuous MF occupational exposure which are 17,5 times lower than those earlier established in Russian Federation and 5 times stricter than those recommended by ICNIRP.

MPLs of continuous CF MF are established depending on the time of the workers' whole body or local (extremities) exposure (table 2).

Table 2
Maximum permissible levels of CF MF occupational exposure

Work time, Hour	MF permissible values, H [A/m] / B [μT] Under exposure	
	Total	local
≤ 1	1 600 / 2000	6 400 / 8000
2	800 / 1000	3200 / 4000
4	400 / 500	1 600 / 2000
8	80 / 100	800 / 1000

The permissible MF value inside time intervals is determined by means of interpolation. If it is necessary to perform work within zones with various MF levels, the total time of work in these zones should not exceed the maximally

permissible length of stay for areas with the maximum MF value. The total permissible work time can be used up at a stretch or in several instalments during the working day.

Similar work is now conducted on the substantiation of 50 Hz MF hygienic standards for non-occupational exposure depending on the MF source type: for MF emitted from permanent sources, such as TLs or electric household appliances, or for short-time human exposure to MP from such appliances and also for those workers who are not professional operators of electric installations but are exposed to such MF sources at work.

One of the most important problems, which is about to be solved, is a parallel hygienic regulation of both components of CF EMF by using the values of current densities induced in the human body by the EMF electrical and magnetic components.

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STATUS AND IMPLEMENTATION OF RUSSIAN HYGIENIC RADIOFREQUENCY STANDARDS

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The first hygienic standards of radiofrequency EMF were established in the USSR in the middle 50s. Upon suggestion by Yu. Osipov and O. Ushinskaya (Leningrad Institute of Occupational Hygiene) the 5-10 V/m power density was adopted as the occupational exposure standard in the 100 kHz-300 MHz frequency range. In 1957 on the basis of the results of the investigations conducted by the specialists of the USSR AMS Institute of Occupational Hygiene and Professional Diseases and S.M. Kirov Military-Medical Academy, temporary standards for centimetric waves were adopted and later extended also to decimetre and millimetre ranges. These standards had a graduated character and permitted the exposure to an EMF power density of up to 10 $\mu W/cm^2$ for 8 hours, from 10 $\mu W/cm^2$ to 100 $\mu W/cm^2$ - during 2 hours, and from 100 to 1000 $\mu W/cm^2$ not longer than 20 minutes.

The first established maximum permissible levels (MPL) of radiofrequency exposure based on a rather small clinical, hygienic and experimental data, and had a rough, temporary character and it was certainly assumed that they needed further adjustment. These hygienic standards have played an important role in the decrease of occupational exposure levels of those working in various industry branches. Today they represent a purely historical interest. Nevertheless, they had played a rather important role in the development of the national factor reglamentation. All consequent MPL modifications introduced with further accumulation of scientific data unequivocally led to an increase of regulation values, which requires a high degree of moral responsibility on the part of those developing the rules and is inevitably resented by the public.

I shall briefly dwell on the consequent changes in the regulation of the factor. In the 60s, on the basis of the results of investigations conducted by the specialists of the USSR AMS Institute of Occupational Hygiene and Professional Diseases, Institutes of Occupational Hygiene and Professional Diseases of Leningrad, Kharkov and Gorkiy, a more precise definition of the 60 kHz-300 MHz EMF occupational exposure MPLs was made. In the 70s the findings concerning the dependency of bioeffects of microwave exposure on the intensity and duration resulted in the introduction of a dose (power) approach, as a more adequate one for occupational exposure evaluation, to the standardisation of the SHF range was adopted. Comparative investigations on the evaluation of biological effects of

continuous and discontinuous exposure were conducted too, but unfortunately their results have been only partly introduced into the practice of hygienic standardisation. The problems of hygienic regulation of the exposure of microwaves with a soft X-radiation and heat combined were well studied too. In the same years the first MPLs for the EMF exposure of the population at large were established. In the 80-90s the power approach to 3kHz-300 MHz EMF hygienic rating was introduced; local (to human hand) microwave exposure MPL was substantiated; 10-60 kHz EMF occupational exposure MPLs were established; the permissible levels of occupational and non-occupational EMF exposures from cellular telephones and video display terminals were regulated; adjustment of some non-occupational MPLs were carried out.

Serious attention to the scientific basis of EMF regulation was initiated in middle 70s. By that time a lot of data on biological effects of radiowaves had been accumulated and there was an obvious necessity of a uniform approach to EMF MPL determination for various frequency ranges and different exposure characteristics (occupational exposure, general population exposure). Guided by the methodological approaches accepted in the domestic hygienic science, it was recognised that the only correct way was to adopt the approaches based on the concept of threshold effects with corresponding hazard criteria. When the transition was made from the hazard effect threshold to MPL, it was thought feasible to make use of the hygienic safety factor differentiated by exposure categories and biological effectiveness. By a hazard effect threshold is understood the exposure level inducing pronounced functional shifts which require exertion of body compensatory systems, i.e., border (between physiological and pathological) states. However, even now not all occupational guidelines are in accordance with the above methodological principles: a lot of MPLs are determined by radiosensitivity thresholds. As to the guidelines for general population, all of them have been established in reference to a non-effective level.

The main hygienic standard now regulating MPLs of RF EMF are GOST 12.1.006-84 «SSBT. Electromagnetic fields of radio frequencies. Permissible levels in workplaces and requirements for control», Sanitary regulations and standards 2.2.4/2.1.8.055-96 «Radiofrequency electromagnetic radiations (RF EMF) under occupational and living conditions», SN N 5803-91 « Permissible limit values (MPL) 10-16 kHz electromagnetic field (EMF) frequency range».

In MPL of occupational exposure in the frequency band of up to 30 kHz the principal regulated parameter is the strength of electrical (E) and magnetic (H) fields, while the time is taken into account to a lesser extent. MPL for a full

working day is 500 V/m and 50 A/m, and for working time exposures of up to 2 hours per day it is 1000 V/m and 100 A/m. .

In the 30 kHz to 300 GHz frequency range the dose approach is used. Along with the strength parameters (E, H, PD) a power exposure (or power load - PL) value for a working day is standardised. The latter is expressed in the frequency band of up to 300 MHz by the product of EF or MF strengths square; in a higher than 300 MHz frequency range – by the product of PD to the duration of exposure: $PL_E = E^2 \times T$ $(V/m)^2 \times h$; $PL_H = H^2 \times T$ $(A/m)^2 \times h$; $PL_{PD} = PD \times T$ $W/m^2 \times h$ ($mW/cm^2 \times h$; $\mu W/cm^2 \times h$).

MPLs of RF EMF intensity (E_{MPL}, H_{MPL}, PD_{MPL}) in the frequency range from 30 kHz to 300 GHz are determined, depending on the time of exposure, from the maximum permissible power exposure PL_{MPL} (table 1) according the following formulas: $E_{MPL} = \sqrt{(PL_{E,MPL} / T)}$; $H_{MPL} = \sqrt{(PL_{H,MPL} / T)}$; $PD_{MPL} = PL_{PD,MPL} / T$.

In any case they should not exceed the established maximum permissible values (table 2).

Table 1.
Maximum permissible levels (MPL) of power exposure (PE=PL) for a working day

Parameter	PL_{MPL} in frequency range (MHz)			
	0,03 - 3	3 - 30	30 - 300	300 - 300000
PL_E $(V/m)^2 \times h$	20000	7000	800	-
PL_H $(A/m)^2 \times h$	200	-	-	-
PL_{PD} ($\mu W/cm^2$) x h	-	-	-	200

For cases of exposure from devices with a moving diagram of radiation (gyrating and scanning antennas with a frequency of rotation or scanning not more than 1 Hz and porosity not less than 20) and local exposures of hands while working with microstrip devices, PD_{MPL} is calculated according to t formula $PD_{MPL} = k\ PL_{PD,MPL} / T$; where k - factor of reduction) of biological effectiveness of exposure, equal to respectively 10 and 12,5 respectively.

Thus, permissible intensity levels depending on exposure time changes are: in the frequency range from 30 kHz to 3 MHz - from 50 up to 500 V/m, and from 5 up to 50 A/m; from 3 to 30 MHz - 30-300 V/m; from 30 to 300 MHz - 10-80 V/m; from 300 MHz to 300 GHz - 25 – 1000 $\mu W/cm^2$ - for continuous exposure; 250 - 1000 $\mu W/cm^2$ for discontinuous; and 312 - 5000 $\mu W/cm^2$ - for a local exposure of hands.

Table 2.
Maximum permissible levels of EMF strength and power density

Parameter	Maximum permissible levels in frequency range (MHz)			
	0,03 - 3	3 - 30	30 – 300	300 - 300000
E, V/m	500	300	80	-
H, A/m	50	-	-	1000
PD, μW/cm²	-	-	-	5000x

x for local hand exposure

In Sanitary Regulations and Standards 2.2.4/2.1.8.055-96, along with MPLs of occupational exposure, are given RF EMF MPLs for general population which were earlier developed by in Kiev Marzeev Institute of General and Municipal Hygiene (table 3).

Table 3.
RF EMF MPL for general population (continuous exposure)

Frequency range, MHz	0,03 - 0,3	0,3 - 3	3 – 30	30 – 300	300 - 300000
MPL	25	15	10	3x	10

x excluding TV stations where MPLs are differentiated for frequency and are from 2,5 up to 5 V/m.

The EMF levels of radars with antennas (or rays) operating in the rotating or scanning mode, have been updated, and in residential areas they should not exceed:

- 100 μW/cm² - for radar of frequency range from 300 MHz to 300 GHZ with frequency of rotation or scanning no more than 1 Hz and porosity not less than 20.

- 10 μW/cm² (6 V/m) in a near zone and 100 μW/cm² (19 V/m) in far zone from radar of special purpose intended for monitoring of the outer space, operating in 150-300 MHz frequency range. The frequency between the near and far zones of the diagram of radiation is determined from the ratio r = D / λ, where r - distance from a source, D - maximum size of a radiating equipment, λ - wavelength of a radiation.

In recent years such RF EMF sources as mobile telephones and video display terminals (VDT) have become widespread. Hygienic regulation of mobile telephones EMF will be the subject of a separate report. As to VDT, in 1996 Sanitary Standards 2.2.2.542-96 «Hygienic requirements for video-display units, personal computers and organisation of work» were approved. In accordance with that document the requirements of Swedish standards MPR 1990 :8,10 and TCO

05, came into force in Russia from 1.01.97. According to those, EMF levels at 50 cm from walls VDT distance should not exceed 25 V/m and 250 ηT - in the 5 Hz-2kHz frequency range; 2,5 V/m and 25 ηT - in the 2-400 kHz frequency range. The validity of this decision is difficult to evaluate unequivocally, as the Swedish standards are based on the criteria of technical accessibility in Sweden. It seems that the domestic standard should be based either on the criteria of safety with allowance for EMF physical parameters characteristics (i.e. on MPLs for corresponding frequency ranges), or on the criteria of technical accessibility in Russia, where miscellaneous VDT are used made in different countries in different years. Furthermore, hygienic control of VDT radiation levels presents certain difficulties.

The hygienic standards, now in force in Russia, are stricter than those in the West. As is known, MPLs at each point in time reflect the level of contemporary knowledge about biological effects of the factor and methodological approaches to their establishment. It is clear, that , on the whole, the empirically established guidelines look less orderly, than those obtained by calculation following the concept of specific absorption (SAR). The fact that our hygienic rules require specification and improvement in future is doubtless. As was already mentioned above, some of MPLs do not agree with the modern methodological approaches to RF EMF regulation. This is due to a number of the reasons, such as:

- imprecise evaluation criteria of thresholds of unfavourable effects, by virtue of which a number of MPLs are based on radiosensitivity thresholds or even on a non-effective level; the principles of extrapolation of experimental data from animals to humans are poorly developed;

- extrapolation of the regularities obtained in the experiments with EMF high levels to low levels. This concerns the dose approach, where the direct dependence of bioeffects on exposure intensity and duration obtained at 250 - 1000 $\mu W/cm^2$ was extrapolated to intensities below 100 $\mu W/cm^2$. It also concerns the approach to the evaluation of discontinuous effects from devices with the moving diagram of a radiation, when upon the results of investigations of bioeffects under low porosity the uniform factor of biological activity reduction «10» was adopted. At the same time there are data precisely indicating power dependency of discontinuous exposure bioeffects. However, along with exposure porosity, hygienic standards should take into account the role of the intermittence factor with the restriction of the maximum permissible PD level;

- underestimation of possible influence of other factors: occupational as well as environmental, and the results of physiological investigations;

- organisational difficulties of maximum permissible levels elevation.

At the same time the domestic MPLs have some advantages:

- they are not the result of mathematical transfer of regularities obtained for the most investigated microwave range, to other frequency ranges. It seems that taking into account the energy absorption dependency on frequency cannot guarantee the equality of biological effects at equal absorption, as it does not take into account the specific features of the interaction between the energy of radiation and the bioobject;

- the methodological approaches to EMF hygienic regulation provide for functional changes. In the light of modern concepts of EMF specific effects on the body it would be apparently incorrect to approach the problem of substantiation of MPLs exclusively from the power viewpoint;

- the accepted solution to the dose approach involving the establishment permissible power exposure for a working day (or possibly for a longer period) seems well grounded, as it involves the factor causing certain modifications in the human health status over comparatively long exposure periods.

We are in complete agreement the opinion of WHO experts based on the analysis of available scientific data, that RF EMF MPL should be at a level from 100 to 1000 $\mu W/cm^2$ with possibly higher levels for some frequencies and modes of exposure and lower levels for general population (WHO 1981, 1990).

A serious obstacle to the improvement of hygienic rules is insufficient knowledge of EMF biological effects, in particular , the dependence of biological effects on physical parameters of the factor and conditions of exposure, interaction of primary mechanisms of EMF of various frequency ranges with body tissues. To solve the above problems calls for fundamental investigations. One can assume that, as a result of accumulation of scientific data, it will be possible to predict EMF biological effects for new frequency ranges and modes of exposure. In other words, hygienic rate setting should become prognostic. In future investigations one should expand the work on the evaluation of EMF of complicated spectral structure effects, radiofrequency genetic effects, combined with other environmental factor effects, specific sensitivity to ELF of various kinds of animals and of humans.

The clinical aspects of the problem require serious attention. Epidemiological studies of different population groups with the purpose of MPL clinical approbation, the remote consequences of long term low intensity EMF effects, and also possible EMF contribution to the development of a number of diseases (primarily, cardiovascular, cancer and some involute processes) are very important.

One cannot help noticing the increased number of publications on weak EMF biological effects in recent years. Some authors see the connection between the carcinogenic EMF effects and the exposure to very low EMF levels. We would like to hope, that future investigations will clarify the issues blocking the progress of MPL development, and will create premises for removal of essential differences of opinion held by scientists of different countries on the evaluation of EMF hazards.

EMF SAFETY FROM MOBILE RADIOCOMMUNICATION SYSTEM Equipment In Russia

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The mobile communication system equipment is an actual source of electromagnetic radiation for the population of many countries of the world. The mobile communication system works on various frequencies 450 - 1800 MHz and various kinds of modulation.

Two various groups of the population can be taken into account due to broad distribution of mobile communication system .

The first group of the population are persons, who do not use cellular telephones, but can be subjected to an EM-radiation from base stations.

Centre of Electromagnetic Safety has conducted measurements of electromagnetic field levels near almost 100 base stations located in Moscow and in Moscow Region. The results have shown, that no EMF hazard exists for the tenants of the apartment houses, on which the base stations are installed or to the surrounding territory, where strict monitoring excludes unfavourable influence EMF on the population.

The second group of the population are persons, who use hand-held cellular telephones. In this case, from our point of view; evaluation of EMF hazard is not at all certain for a number of reasons.

First of all, the scientific groups working in the field of evaluation of biological effects of EMF and their measurements had not been prepared for the appearance of such a peculiar EMF source of exposure, which is held so closely to a person's head (2-5 cm).

During the use of the cellular telephone the brain and peripheral receptory zones of the vestibular and acoustical structures and the retina are bound to be

subjected to EMF exposure with various carrier frequencies and modulations with various distribution depths and magnitudes of the absorbed dose, with various periodicity and overall exposure duration.

Now there are only experimental reliable data indicating that, during exposure of central structures in the brain, EMFs with a specific absorbed dose from 0.4 W/kg or 40 $\mu W/cm^2$ and above, temporary responses can arise which can be regarded as irritant as well as pathological responses with consequent compensation. Similar responses were also obtained on the volunteer subjects.

The investigations on volunteers conducted by us (Centre of Electromagnetic Safety, SRC Russian Federation - Institute of Biophysics) using three standards (450, 800 and 1800 MHz) have shown a possibility of a brain response to short-term cellular telephone EMF exposure (only based upon the criterion of modification of brain biocurrents).

The data on the development of possible remote consequences for users of cellular telephones are unavailable yet. The results of the tests conducted on animals with modulated EMFs from cellular telephones require an additional refinement since whole body exposure, instead of local exposure of the head, was used.

In Russia the Hygienic specification 2.1.8./2.2.4.019-94 "Interim permissible levels (IPL) of the effect of electromagnetic radiation created by systems of cellular radio communication", recommending the temporary permissible EMF level of 100 $\mu W/cm^2$ for users of radio telephones, 200 W h/cm^2 during a shift for workers and a power flux density of 10 $\mu W/cm^2$ for the population living near the base station .

The existing hygienic rules and results of the experimental investigations on biological effects of EMF at the frequency of 950 MHz were taken as a basis for the substantiation of MPLs for users of radio telephones. Those established that the level of 250 $\mu W/cm^2$ acting daily for 3 months can be considered as the threshold of harmful operation. The difference in the absorption of energy in the 800-1000 MHz range between small-size laboratory animals and the human head is a factor of 15; the extrapolation factor for the exposure duration of possibly 50 years is a factor of 7.5; and the hygienic accumulation factor is 5. Hence the MPL of power flux density = (250 x 15) / (7.5 x 5) = 100 $\mu W/cm^2$.

Machines and equipment for instrumental monitoring the EMF levels created by cellular radiotelephones were developed on the basis of various

measurements of the "free space" EMF in the near field zone taken with special broadband isotropic field probes which are now available. The latest foreign data on the evaluation of absorbed doses in phantoms of the head are taken into account.

The problem of a criterion for the evaluation of danger remains debatable: specific absorbed rate (SAR) or power flux density, the concept of "power load " is not used.

As the most promising direction of investigations on the evaluation of danger of mobile phones we see broad implementation of clinical-physiological investigations on volunteers with the use of various modes of EM-effect (including modulation) and terms of observation. Accumulation of data on possible nearest functional health damage to users of cellular telephones, will make it possible to considerably speed up the development of reasonable normative documents and to conduct necessary educational work among the population.

PRINCIPLES OF ENSURING ELECTROMAGNETIC SAFETY IN POWER INSTALLATIONS

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Introduction

Power installations are sources of biologically significant 50 Hz magnetic field (MF) levels. Extremely- and ultra- high voltage power installations are sources of both low intensity MF and high level commercial frequency (CF) electric field (EF). It has been established that EF and MF long-term exposure can lead to unfavourable changes in the health status of workers and population.

EF and MF exposure exclusion is achieved by means of protective measures. There are principle differences in protection from EF and MF. Elimination of EF exposure is done mainly by technical means that either ensure the decrease of EF levels at work places or rely on screening clothes. For MF elimination one has to be content with only practical measures to reduce the working time in MF exposure conditions. In this connection, the implementation of electromagnetic safety principles can best be viewed on the example of EF.

Brief history

The studies of ecological safety of power installations in the USSR were begun in 1950s when no one in other countries addressed that problem yet. This was no surprise, since our country was the world pioneer in the field of construction of extremely high voltage transmission lines and was the first to face the electromagnetic ecology problems. Conclusive data on EF unfavourable effects on humans made us investigate this problem and develop protective measures.

Russian scientists never thought of dramatising this situation, but neither did they choose to ignore the possibility of EF unfavourable effects on humans. It was considered that it would be better to exclude the exposure by protective measures than to pay dearly for the inaction later. Considering the complexity and long-term character of necessary medical and biological investigations involving the forecast of possible (also remote) consequences, the anticipation protection principle was suggested in practice. As a result, from the 1960s screening suites and protective screens were used by 500 and 750 kV substation personnel and linemen. These protective measures made it possible to normalise the occupational environments in extremely high voltage (EHV) installations. But this seemingly

positive solution produces negative consequences too. Some specialists expressed their doubt about the very existence of the problem, and that had a negative influence on the continuation of work. Additional difficulties were related to the attitudes in other countries where no due attention was paid to the problem of electromagnetic safety. Some interest to this problem appeared after the publication of a report by Soviet scientists in CIGRE Proceeding in 1972 (Korobkova V.P. et al., 1972) [1]. This publication triggered full-scale investigations in the USA and in other countries.

At government level, there has always been full understanding of the importance of the CF electromagnetic safety problem in Russia. In the middle of the 1960s a comprehensive investigation was carried out in accordance with State Programme " Main directions of work for excluding of 50 Hz electric field effects to staff and population". This programme included three directions of studies:

- investigation of EF levels and distribution in substation territories and near overhead transmission lines (TL) as well as work conditions in these installations;

- medical and biological analyses of the personnel health status at work places, in clinics, and physiological studies in model conditions for the evaluation of the nature and possible consequences of EF exposure for humans, and development of safety standards of exposure for personnel and population;

- effective and economical protective measures development and implementation, including the development of type designs for power installations.

- The implementation of this Programme enabled a speedy solution of the final objective - protection from EF effects. It was a success which was due, in part, to the right organisation of medical and biological investigations in collaboration with power engineers.

EF hygienic standardization principles

Introduction of protective measures is impossible without compulsory State standards established at the federal level. Scientifically substantiated standards must be based on biological effect mechanisms which have not yet been investigated in full. Therefore, the exclusion of EF unfavourable effects strategy included at first the fixation of permissible levels before the fundamental

investigations on EF mechanisms were completed. Hygienic standards were substantiated by the determination of threshold levels of statistically significant physiological changes, and with different hygienic safety factors for workers and population. These safety factor values depended on technically achievable and economically justified levels too. Occupational exposure hygienic standards [2,3,4] in our country have remained practically unchanged for over 25 years, and there are no good grounds for their revision in the near future. Population hygienic standards [5] have been in force for about 15 years about and are not likely to be changed soon.

EF hygienic standards in our country were developed with regard for the necessity of exclusion of all of types of EF effects, such as:

- direct (biological) effects after long-term and systematic (every day) EF exposure if the EF levels are higher than permissible;

- electric charges (pulsed current) effects that are generated when people touch earthed parts of equipment, large or long metallic constructions, grass etc.;

- exposure to the currents flowing through human body if the person is in contact with large structures or machines insulated from the earth.

The two latter exposure type effects are evaluated equally all over the world, but as far as the EF biological effects are concerned data are contradictory in different countries. Many foreign publications referring to [1] state that EF biological effects have not been found outside Russia, and those were founded only on subjective neurological complaints by workers and thus cannot be considered conclusive.

- Actually in the former USSR a significant complex of hygienic, clinical, physiological and experimental investigations was performed, that provided convincing objective information on EF biological effects on humans. So it is possible to speak about the absence of this information in [1], but not about its absence in general. Besides, the biological effect in various manifestations has been revealed by a majority of the contributors abroad, and the contradictions frequently arise not in the findings of such investigations, but in their interpretation.

- According to the principle of hygienic rating of any hazard factor adopted in our country, EF MPLs are determined on the assumption that permissible

occupational EF exposure (in all its manifestations) during the whole working life should not result in traumas, disease or health status changes during the process of work, or in the remote time of life of the present and next generations.

- The following deserves a special mention: even the changes within the limits of physiological standards are considered by us inadmissible, if they result from the effect of the EF-exposure, whose unfavourable effect on humans was revealed, as stated above, in the 1960s.

- MPL regulation with allowance for of all kinds of EF effects is carried out separately for staff (practically healthy people) and general population including children, old men, pregnant women, patients with a weakened immune system. The standards for staff are taken into account for the designing of substations, standards for the population - for the designing of overhead transmission lines (TL).

Direct EF effects

The data of long-term biomedical investigations on direct EF effects, including inspection of places, clinical and other investigations, have enabled us to make the conclusion that permanent everyday, 6-8 hours per day during several years 20-30 kV/m EF exposure can cause health status changes and disorders (more often functional) and have a cumulative character. The disorders which required medication were fixed also, which was apparently a consequence of failure of adaptation and was characteristic of persons with increased sensitivity to EF. Nothing similar was observed in the control group consisting of 110 and 220 kV substation staff, i.e. executing the same type of work in the same regions, but without high level EF exposure. This conclusion was made in our country when 500 and 750 kV substations were under construction without measures and means ensuring a decrease of EF strength. Then it was established, that a non-systematic EF exposure, typical for the workers servicing TL of 330 kV and higher, does not result in expressed changes and disorders. Moreover, it can be accompanied by a stimulating effect on the immune system of a person, thus resulting in the health status parameters that are objectively better than in the controls. Since then in the former Soviet Union no data has been obtained which are indicative of the inaccuracy of the conclusion made many years ago. It is also true that there has been no confirmation of its correctness either, but that would have been impossible as the conditions described practically cannot be reproduced in a laboratory, while the substations have long been equipped with protective means, and the working

times have been sharply reduced - and it is now impossible to speak about a systematic exposure.

Today, on the basis of the investigations and observations which have been conducted in Russia practically without interruption since late 1950s but for certain reasons have not been widely publicised, one can confidently state that human response to EF exposure is unspecific, not sufficiently distinguished from that of a continuous stress, frequent change of biorhythms, effect of a noise etc. Unlike such hazard factors as ionising radiation, X-rays and some others, EF does not devastate human body. It is only possible to assert that a long-time and systematic EF exposure weakens the body protective systems increasing the risk of certain unfavourable changes and disorders, first of all in the central nervous system.

Electrical discharge effects

Electrical discharges, as is known, arise because of the voltage difference between human body and various objects, which people might come into contact with while in an EF. This voltage difference can be conditioned by the presence of EF voltage in the body and (or) on an object, if they are insulated from earth. The contact results in a pulsed discharge current passing through human body, causing painful irritation or, at least, discomfort.

The discharge exposure results in the violation of the processes of excitation and inhibition in the cortex thus stimulates involuntary motor responses, especially dangerous while working at great heights, when the affected person might fall. Therefore even a short-term discharge exposure is inadmissible (unlike short-term direct EF exposure). Long-time discharges exposure accompanied by strong pain can break the heart and breath rhythms.

Both in Russia and abroad, it is recognised, that discharges provoke stress development and other harmful phenomena. It is obvious that they should be eliminated.

Flowing current effects

The direct physical reason for flowing current is the capacitive connection of a conductor, with its conducting elements under tension, located in EF. By touching such an object insulated from the earth, the person shunts this insulation. As a result, the current which was earlier flowing down from the object to the earth partly begins to flow through the body.

The share of the current flowing through the human body upon contact with a perfectly insulated conducting object is approximately 70 % of the total, but in practice does not exceed 50%.

The flowing current depends on EF strength, dimensions of the object, quality of its insulation from earth, arrangement in relation to the conducting elements and other factors. Therefore it varies over a wide range. In many cases this current becomes perceptible, and in some, for example, at E >20 kV/m - can exceed the MPL of let-off current, when because of muscular convulsion the person cannot independently break the contact with the object. In this case the flowing current can be fatal.

Inside substations and close to TL, in accordance with the compulsory staff safety rules all large-size objects are subject to mandatory earthing. Therefore the flowing current is taken into account only for the EF regulations for general population.

Standards for staff.

The development of EF MPL for staff included:

- research of EF levels at work places and timing of the presence of the personnel in places with certain strengths while working in substations or on extremely high voltage (EHV) TL, with the purpose of using these data for laboratory investigations of EF effects on volunteers;

- comprehensive medical and physiological evaluation of staff at work for the determination of the character of unfavourable EF effects;

- physiological investigations of the effects of EF of various strengths and different exposure times on practically healthy people in laboratory conditions.

Soviet EF standards for workers [3,4] are known.

With reference to the staff servicing EHV substations, only two values of permissible EF strength are practically in use: 5 and 15 kV/m. The first is for all kinds of works without time or work type limits (including work at heights); the second, implementing the known «safety by time» principle - only for survey of the equipment from the ground, provided that the survey is not accompanied by

contact with constructions, equipment, machines etc., when pulsed current exposure is possible.

The EHV TL servicing staff uses as permissible only one strength value - 5 kV/m - for all kinds of work, including work at the towers, ground-level inspections of TLs earth, clearing of the route etc. If the strength is higher than 5 kV/m, protective means should be applied.

General population guidelines

Within the framework of the development of EF regulations for general population, a study was conducted on the living conditions of the population in the vicinity of EHV TLs (residence, of agricultural and other works, rest, mushrooms or berries collection etc.), as well as laboratory and field studies (on animals and humans) on CF EF biological effects. It was established, that various groups of the population depending on the living conditions and character of activity could be exposed to EF of different duration. Residing close TLs can lead to round-the-clock systematic EF exposure, if the EF level inside a house exceeds MPL. Outside the house, in a residential area, a long (but not day-and-night) stay of the people is possible. In a populated area systematic stay of the same persons close to TL practically never occurs, and the duration of single visits of these areas is usually limited to 3-5 hours. In unpopulated areas, where agricultural works are carried out, EF exposure may occur only during manual handling of plants, harvesting of agricultural production, and putting the cattle to pasture. The timings taken have shown that the maximum duration of stay in EF for those reasons is 1.5 hours. The expose durations obtained were used in experimental studies with the purpose of development of EF guidelines for general population.

The EF regulations for population [5] are known. However, it might make sense to repeat them together with explanations mentioned below. Thus:

Inside residential buildings, where the round-the-clock constant stay of people (including children, old men, patients) is possible, to ensure the conditions for elimination of direct EF effects the level should not exceed 0.5 kV/m, including the windows facing TL.

To eliminate direct EF exposure or perceptible discharges and flowing currents, the EF level should not exceed 1 kV/m on balconies, terraces and verandas of residential and public buildings, including garden houses, and also in areas close to residential building as well as in gardens and kitchen gardens, garage co-operatives areas and public transport stops, where a long (but not day-

and-night) stay of the people is possible. In the areas of children's playgrounds, and other places of lengthy presence of children, the EF strength should not exceed 1 kV/m even if these zones are located outside residential areas.

The EF level should not exceed 5 kV/m, (with the elimination of discharges and flowing currents exposure too): in populated areas, outside of residential building zones (urban territory of cities within the boundaries of their prospective development for the next 10 years, suburban and green zones, resorts, villages within their limits), where non-systematic stay of limited duration in EF is possible.

At intersections with roads of I-IV class, to eliminate discharges and flowing currents exposure, the EF level should not exceed 10 kV/m. Otherwise stopping and/or parking of automobiles should be prohibited there.

To ensure dischages and flowing currents elimination, EF levels should not exceed 15 kV/m in the unpopulated areas (vacant districts, even though frequently visited by people and accessible to transport, and agricultural territories), where non-systematic stay of people (manual handling of plants, harvesting of agricultural production, and putting the cattle to pasture) for no more than 1,5 hours per day is possible.

In almost inaccessible regions (not accessible to transport and agricultural machines), where only an occasional short-time stay of people is possible, to eliminate direct EF effects, EF levels should not exceed 20 kV/m. Measures on excluding the people from such areas should otherwise be adopted.

With EF strengths over 1 kV/m, it is necessary to eliminate perceptible discharges and flowing currents exposure by earthing large-size conducting objects, machines and mechanisms close to TL. Russian mentality may accept the validity of such demands on non-occupational exposure, but it is impossible to guarantee compliance.

EHV TL phase conductors distance from the ground determines the permissible EF strength in unpopulated areas, therefore it is economically unfeasible to apply more rigid regulation. If a combine harvester (its trailer or another agricultural machine or device) is not properly earthed, discharges and flowing current exposure can, of course, take place, but these effects can not be dangerous for adults even at the worst, improbable case (a combine harvesters with a trailer is in parallel to the extreme live TL wire, the ground is dry and the tyres clean), the let-off current will be lower than 6 mA [6]. Besides, the flowing current

exposure is possible only when the driver gets off the machine touching it and the earth simultaneously. If a passer-by touches it, a discharge producing a painful irritation will occur and he will jerk off his hand before the flowing current stars flowing through the body. Complete elimination of perceptible dischages and flowing currents would require, as stated above, a drastic restriction on EF strengths under TL and a corresponding increase in the TL tower height increase that would make the use of 750 kV or higher class of voltage TLs impossible. Partial measures are not logically sound.

Protective measures

Substations staff protection

The long-term experience of works on substation staff protection has shown, that the restriction of staff work time in EF ("protection by time"), as an alternative to the decrease of EF strength is unacceptable: it would require an unacceptably frequent change of the personnel to ensure the necessary amount of works, which is unreal. It has been established also, that the decrease of strength by electrostatic shielding only is not possible, since the volume of shielding is so great that substation maintenance is impossible (no movement of machines and mechanisms, difficulties with equipment installation etc.). Therefore in Russia, worker protection in new EHV substations is carried out in two stages. The first stage - application of such design-layout solutions, which ensure general decrease of EF strength in installation or in separate cells by 1,5-2 times (usually to 15 kV/m). The second stage - application of shielding devices that reduce EF strength at all work places to permissible levels - 5 kV/m. The two-stage protection ensures not only a considerable to reduction of shielded areas within substations, but also makes it possible to preserve the long-established system of maintenance service of the equipment. Its application is regulated by a directive document [7].

The most effective first stage biological protective measures are: the assembling of equipment on elevated bases, which not only increases the distance from energised conductors, but also strengthens the shielding effect of the bases; the use of disposition of middle and side phases, for maximum EF compensation; application of arrangements without the upper circle of buses, that simplifies protection during repairs on switches; increase of the distance between circuit breakers and modular buses; parallel disposition of bus break switches application; special foot tracks in outdoor switch-gear arrangement; moving the buildings away from zones of EF influence etc.

The stationary shielding devices [8] were developed to be installed in new substations. However, many of them may also be installed in the existing substations (if insulation distances are kept). The screens are made from standard elements (cables) with optimum parameters ensuring necessary efficiency. The optimisation of screen parameters is reached, due to the use of the effect of migration of EF branch point in shielded space when changing the number of cables number and the distance between them. The overlapping of this point with the location of human head automatically ensures the most favourable EF distribution in a shielded space.

Recently screening clothes have become the main means of staff protection. It has become possible due to the creation of a new generation of screening clothes made from a new shielding fabric.

Electroconductivity of the new fabric is achieved by coating certain common fabrics (by electrochemical method) with alloys of a number of metals (nickel, iron, cooper, cobalt), which are put on the surface of the fabric activated by sulphides of zinc, cooper, iron, silver and palladium. The coating ensures good adhesion and, accordingly, stability. New electroconductive fabric shielding efficiency, and consequently, and its protective properties, are 10-15 of time higher, than those of the electroconductive fabrics used earlier. Therefore protective clothes ensure an ideal protection from EF, irrespective of its strengths. The optimum combination of protective and hygienic properties is achieved by the choice of fabric with a specific denseness.

Besides its high protective properties the new fabric has a pronounced therapeutic effect providing correction of the health status. In particular, it reduces pain in joints and backbone, normalises blood pressure. The use of the new conductive suit reduces tiredness, thus reducing risk of electric traumas and increasing labour productivity. The therapeutic properties of the new fabric have been confirmed by investigations made in a number of Moscow clinics. The fabric is recommended by the Ministry of Health of Russian Federation for application in medical practice.

Protection of linemen

Protection of linemen performing all kinds of work, including energised conductor live-line maintenance, is carried out in conductive clothes only. Other protective means are applied very seldom.

Protection of general population

The necessity of protection of the general population living close to EHV TL from EF exposure imposes serious restrictions on their construction. TL building and operation must ensure safe and harmless living conditions for general population, whether living there, conducting agricultural and other works or temporarily visiting sites close TL. This is done through elimination of EF exposure.

To decrease EF strengths in places where people stay one applies active protection, by choosing appropriate design or location of TL in relation to the area or objects to be protected, and also passive protection by shielding certain areas (garden lots, garages etc.). Sometimes both methods of EF level decrease are used thus achieving the objective at lesser cost and minimal damage.

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Human responses to the Electromagnetic Radiation from cellular telephones

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The basic objective of the research

To obtain information about the impact of the electromagnetic fields from mobile telephones on the health of humans associated with basic and advanced cellular communications for single short duration exposures.

Methods for the study

Observations have been made on a complex of clinical/physiological parameters including physiological, biochemical, clinical and psychological indicators of mobile telephone users characterizing their functional condition before, during and after using mobile telephones (hereinafter - telephone) from the various cellular communications system standards.

Gathering of the required data was carried out in the following way:

- polyparametric evaluation of the functional condition of the human organism under the condition of "sham" operation of the telephone (control series).
- evaluation of the same indicators following the same measurement procedures under the conditions of the identical operation of telephones from three different standards.
- analysis of the dependence of possible electromagnetic field (EMF) bioeffects on the duration of user's operation of the telephone for 5, 10 and 30 min.

Four series of measurements were carried out in order to address the problems posed: an analysis of EMF bioeffects from telephones of three different standards and a control series.

Each subject took part in all four series in random order. They were all carried out in the same way.

- examination by the duty physician,
- carrying out of the psycho-physiological tests,
- taking of a saliva sample for radioimmunological biochemical analysis,
- recording of physiological indicators (EEG, EKG, breathing, tremor and myogram); measurements carried out prior to, during and after real or "sham" operation of the radiotelephone,
- a repeat sample of saliva for radioimmunological biochemical analysis, and
- a repeat carrying out of the psycho-physiological tests.

Organization of the experiment

In carrying out the study each telephone was adjusted for maximum radiated power. This was achieved by simulating the worst radio communications conditions between the telephone and the corresponding base station. With this goal, the telephone was placed in an anechoic chamber and the electromagnetic shielding of the anechoic chamber was changed so as to select the worst communications conditions. Adjustment of the operating regime was done using the indicating scale of the telephone. In parallel with this, dynamic measurements of the magnitude of the electromagnetic field was carried out at a distance of 20 cm from the antenna of the telephone. This was done using an EMR-20 electromagnetic field measuring instrument remotely controlled with a PC.

While the experiment was being carried out, the subject was comfortably seated in an armchair. The radiotelephone was turned on and off from outside the anechoic chamber so that it could be mounted in a stationary position on a stand in the immediate proximity ($\approx$ 3 - 5 cm) from the left ear of the subject (see Figure 1). Therefore the subject and the worker operating the measurement and control apparatus did not know which model of telephone was being used.

Figure 1. Volunteer subject during test

Characteristics of the Subject Group

The group of subjects consisted of 10 males aged 23 to 47 years in apparent good health.

Characteristics of the cellular telephones used

Parameters of the telephones used during the study are shown in Table 1.

Table 1 Technical parameters of the cellular telephones used

The standard of cellular communication	NMT - 450	GSM - 900	GSM - 1800
Model of phone	Nokia 450	Siemens S4	Motorola PT-9s
Operational frequency, MHz	453 - 457.5	890 - 915	1710 - 1785
Output power (under the manual), W	1.0	0.25	0.125

Characteristics of the methods used to evaluate the organic condition.

A complex of methods designed to investigate the responses of the CNS and the organism as a whole has previously been developed. Its purpose was to solve the problems of hygienic standardization for low intensity EMFs over a wide range

of frequencies. It included electrophysiological, biochemical and psycho-physiological studies of both acute and chronic EMF effects.

The electrophysiological studies include the examination of a simultaneously recorded complex of electrophysiological indicators describing the activity of systems: central nervous, cardiovascular, muscular and respiratory. This procedure provides a maximum of information for the evaluation of the biological significance for the organism of low intensity short duration exposures to physical factors.

The biochemical measurements permit the evaluation of the influence of the physical factor at work on the hormonal system of the anterior lobe of the hypophysis. They combine in the evaluation of changes in the concentrations of hormones which characterize the integrative activity of the hypophysis both on tissues (and target cells) and on other biochemical systems of the organism. These are adrenalin, noradrenalin and cortisol.

All the traditional methodological techniques have been modified and supplemented in accordance with the physical factor at work.

The methodological modification of artifactless electrodes adopted in the experimental set ups for low intensity EMF irradiations has shown itself to be satisfactory with regard to the quality of the physiological information and the so-called microwave "artifact." A special complex of electronic apparatus permits the simultaneous recording of the whole range of electrophysiological information described above and to partially process it at once during the process of taking the measurements. The presence of a computer in the complex of apparatus permits processing and carrying out corrections of the statistical evaluations of all the information obtained.

At all stages of the investigation, provisions were made for obtaining quantitative data and for statistically analysing it individually for each subject and for the study group as a whole. The statistical analysis of all the indicators was carried out on a computer using parametric and non-parametric criteria.

Recording biocurrents from the brain (EEG).

The recording of biocurrents from the brain was done on the right and left hemispheres in the frontal, temporal and occipital regions.

Because the EEG electrodes were situated in the zone of influence of the EMFs from the radiotelephone, the use of metallic pickups and wires was incorrect in the circumstances. Therefore artifactless electrodes were used - (poly)vinyl chloride tubes and cups filled with a physiological solution based on agar-agar with the consistency of a gel. Such electrodes have been approved through earlier work for use under the influence of EMFs. Their resistance is approximately 1 MΩ.

Spectral characteristics of the EEG.

Berg-Fourier analysis of the EEG from six regions of the brain (central frontal, temporal and occipital, in each case right and left) was carried out using a forty second epoch with the help of a specialized mini computer directly during the investigation. Average spectra were built up for 5 min at a time repeating the measurements for background (10 min), during the period of EMF influence (5, 10 or 30 min) and constantly after the radiotelephone had been turned off.

The EKG, EMG, tremor and breathing sensors were placed at a distance from the EMF source (on the hands, legs or the body) and were as conventionally used.

The psychophysiological tests were directed at revealing signs of fatigue (Shulte tables, answers to lists of special questions, evaluation of the precision of reacting to a moving object).

Evaluation of the hormonal status was directed at the determination of the dependence of changes in the concentrations of corticosteroids and insulin before and after using the radiotelephone and also at establishing the interaction between the levels of adrenalin, noradrenalin and corticosteroids before and after using the radiotelephone.

The evaluation of the levels of hormones in the organism of the subject was carried out using the method of radioimmunoassay on a biological fluid. For this purpose samples of saliva in the amount of 4 - 5 ml were collected from each subject before and after use of the radiotelephone.

Results

Results of the CNS study

The spectral characteristics of the EEG in the studies with the various types of radiotelephones are presented in Figures 2 - 5. The dynamicEEG spectra (for an

analysis epoch of 40 s) are given with the 5 min average spectra. For correctness of comparison, the data presented in the illustrations were obtained on one and the same subject in the various series.

As a result of statistically processing the bioelectrical activity indicators of the brain, The following conclusions can be made.

During and after the period of using the radiotelephone, the EEG spectra were strengthened, compared to the original background and control, mainly in the alpha region.

A significantly larger number of cases of strengthening of the alpha rhythm were observed in the series with the "GSM-900" and "NMT-450" telephones than in the control series with "sham" operation of the telephone. A noticeable difference associated with the duration of usage of the radiotelephone (continuously for 5, 10 or 20 min) did not appear. Supplementary studies are necessary for resloving the questions of the effectiveness of the influence of EMFs from these telephone standards.

In the majority of the subjects a significant strengthening of the alpha rhythm was observed, principally in the series where they were using the radiotelephones.

The final result indicates that there exists a significant change in the bioelectrical activity (EEG) of the human brain as a result of the use of radiotelephones of the types "GSM-900" and "NMT-450."

Results of the investigation of the cardiovascular, respiratory and muscualr systems of the organism

The parallel analysis of the pulse frequency and breathing, the electromyogram, tremor and arterial pressure made it possible to determine whether these changes in the CNS arise at the level of the organism and whether, thereby, changes occur in the condition of the organism as a whole. Reliable indicators were not obtained for the group of subjects for even one of the indicators investigated. It was demonstrated that all the monitored indicators were within the bounds of physiological norms. Their possible variations (even the significant ones) had an erratic character which was observed, for example, in the same percentage of cases, both in the controls and under conditions of irradiation with the EMF from a cellular telephone.

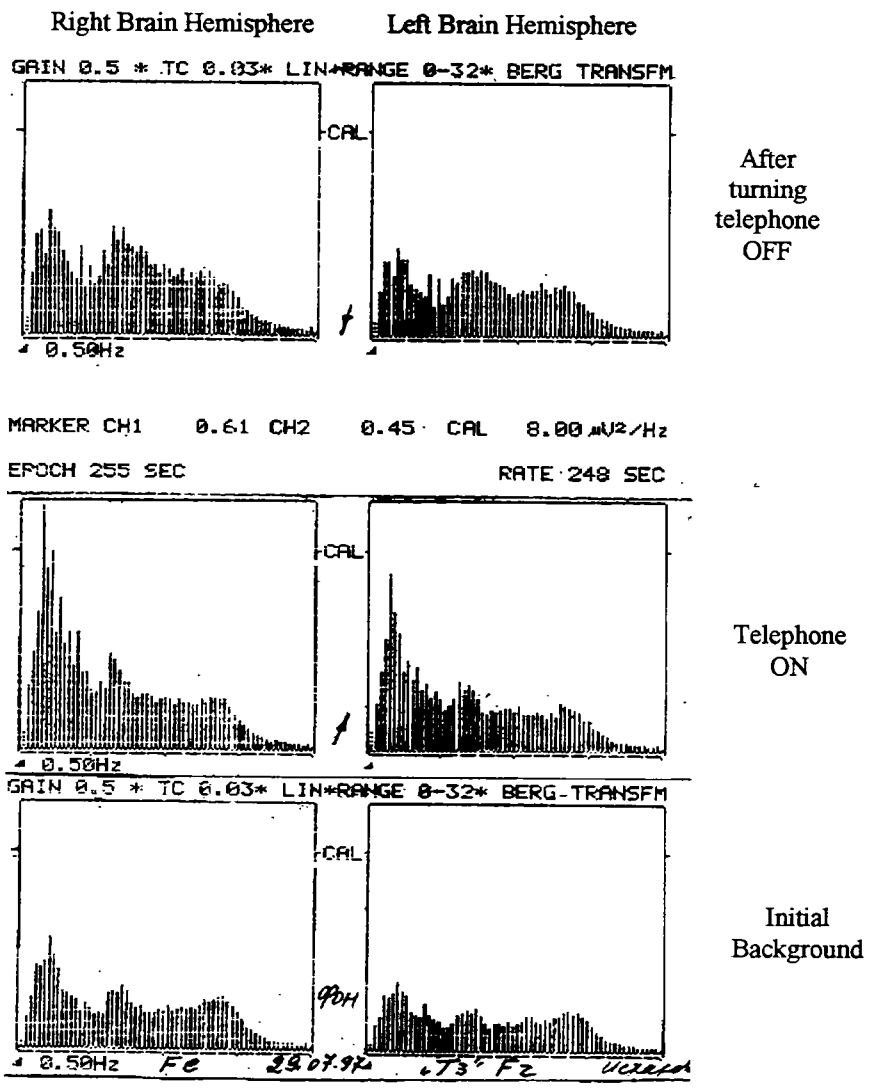

Figure. 1. The EEG average spectra amplification in a series with the NMT-450 mobile phone (volunteer I-v)

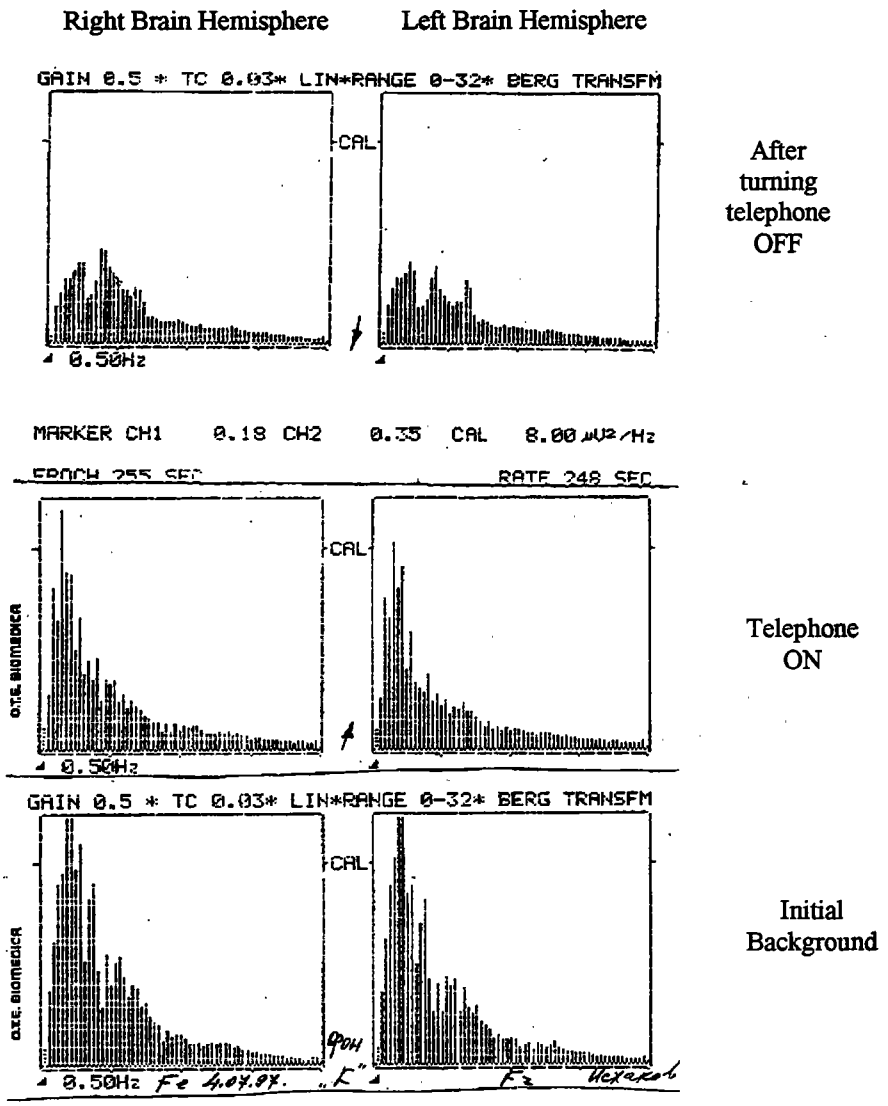

Figure 3: Average EEG spectra for subject I. in a control study with sham operation of the telephone

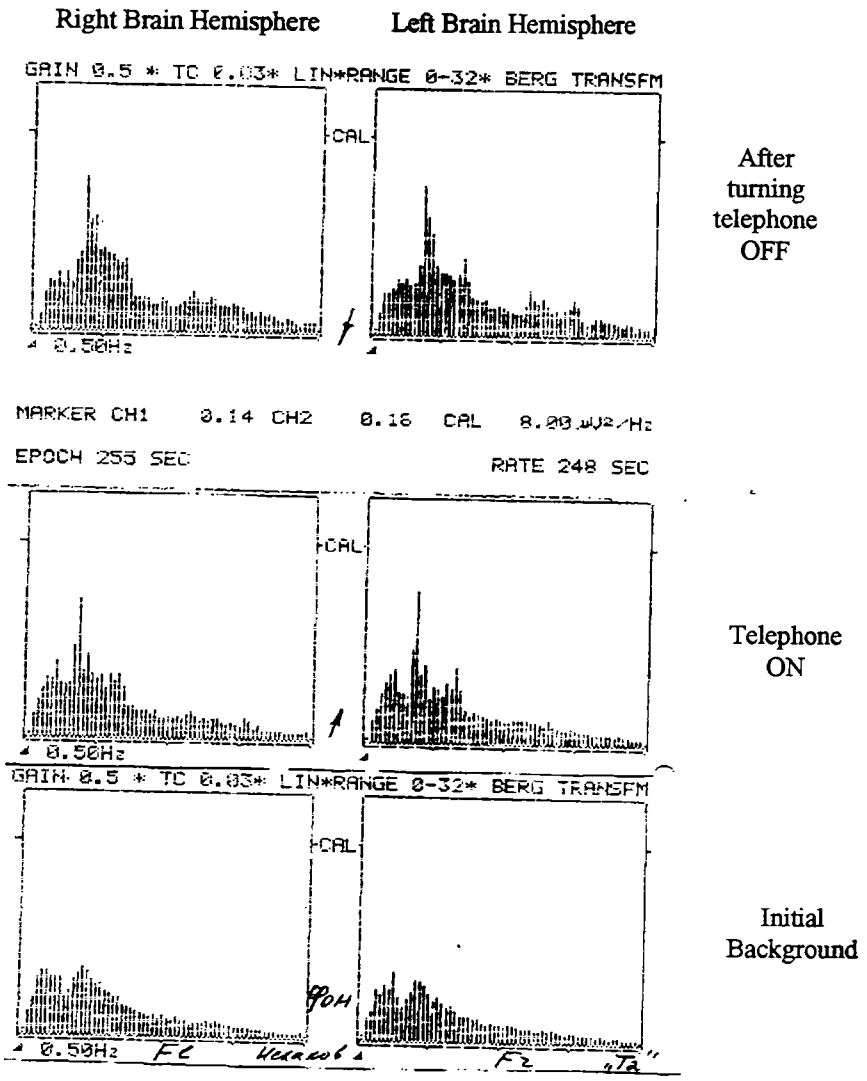

Figure 4. Strengthening of the average EEG spectra in a series with a GSM-900 standard telephone for subject I.

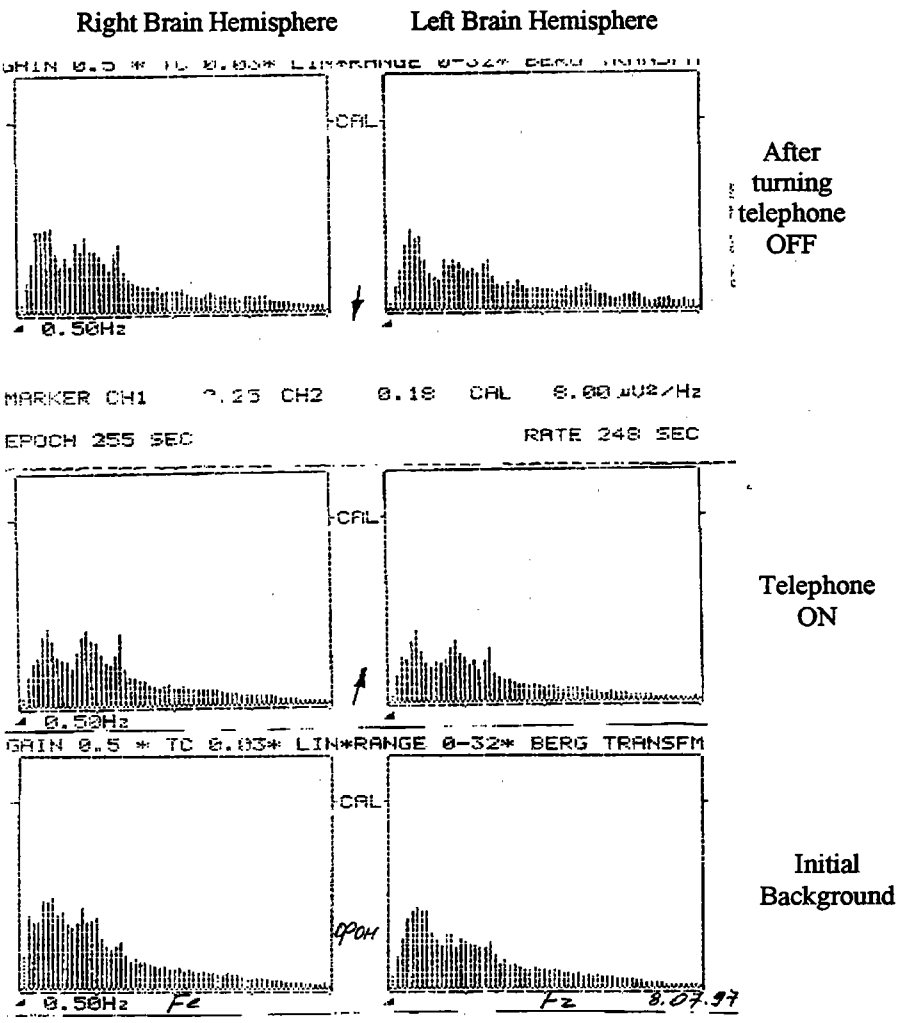

Figure 5: Absence of changes in the average EEG spectra in a series with a GSM-1800 standard telephone for subject I.

Results from studying the psychological status of the subjects

The data from the successful completion of the psychological tests indicate the absence of changes.

Results from the study of the hormonal status of the organism

The short duration use of a radiotelephone by the subject does not lead to any significant changes in the catabolic rate of the active forms of the catecholamines: adrenalin and noradrenalin.

There was observed a limited tendency towards an increase in the level of cortisol in the saliva of the subject after the use of the radiotelephone which can be interpreted as the existence of a weak physiological stress on the organism.

The study of the sympato-adrenal, adrenal and the insulin systems forms a basis for suggesting that the short duration use of radiotelephones from the standard systems studied correlates with a weak electromagnetic effect on humans.

Conclusions

The studies carried out record the fact of the influence of the EMFs from a cellular telephone on the brain of the user. The data obtained agree completely with our (previous) data and the data of other reserachers on the impact of low level single occurrence actions of physical factors of a magnetic or electric nature on the (human) organism.

The EMFs from cellular telephones of the NMT-450 and GSM-900 standards elicited relaible changes in the bioelectric activity of the brain. In the majority of users, during and after the period of irradiation with the electromagnetic fields from radiotelephones, compared to initial background and controls, the alpha region in the EEG spectra of the brain increased. These modifications do not go beyond the bounds of the normal functioning of the CNS and may be interpreted physiologically both as a protective response to a biologically weak stimulus for the CNS and, for single EMF exposures, as weak in its biological significance. The reaction depended on the initial physiological background of the organism and had tendency towards cumulation (build-up).

The absence of reliable changes in the bioelectric activity of the brain in case of using the GSM-1800 standard phone (among the group of observations)

permits it to be characterized as having the least impact on the functioning of the user's CNS.

The changes in the bioelectric activity of the brain did not depend on the exposure duration (5, 10 and 20 min uninterrupted) but persisted over the course of the 15 - 20 min after completion of the exposure.

The absence of reliable shifts in the series of somatic indicators (arterial pressure, heart beat frequency, EKG, electromyogram) and the ambiguous changes in the neuroendocrine system indicate the subthreshold character of the reactions of the organism as a whole.

The results of the research carried out also demonstrated the absence, on the whole, of clinically meaningful impacts of single 5, 10 or 30 min uses of radiotelephones of three (specifically studied) types: NMT-450, GSM-900 and GSM-1800.

The facts established in the course of the present study require further study (replication and elaboration).

Statement of a problem for further research

To develope the suggested research it is advisable to conduct, in the plan for studying the dependence of bioeffects from an initial state of the user, by including groups for background, age, state of health, conditions of exposure (possibly accompanying other weak CNS stimuli, subjects of conversation, smoking, etc.) and the mode of use of the cellular telephone. These further researches will help to reveal and to elaborate the conditions under which unfavourable impacts of cellular telephones on the user's health occur or the absence of clinically significant modifications will be reliably established.

INVESTIGATION OF THE FUNCTIONAL CONDITION OF THE CENTRAL NERVOUS AND CARDIO-VASCULAR SYSTEMS AMONG MOBILE TELEPHONE USERS

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The rapid advances in mobile systems for radiocommunication, in particular cellular telephones, has lead to a considerable increase in the level of electromagnetic fields the adverse effects of which influence the greater part of the community both in occupational and residential situations.

Cellular radiocommunications systems are becoming ever more widely used because of their ability to utilize very effectively the radiofrequency region of 400 to 1200 MHz which is assignd to their operation and their ability to achieve connections between substantial numbers of subscribers. In foreign countries, such systems are significantly outstripping other forms of telecommunications on the basis of rate of development.

In studies carried out by us previously (1), it was established that the cellular phones presently in use like Nokia, Benefon, Maxon, etc., with output powers of 1.0 to 5.0 W, are sources of high intensity SHF (microwave) radiation, with levels ranging from 250 to 1650 $\mu W/cm^2$ which exceeds the permissible level for users (2) by 2.5 to 16.5 times, and produces an adverse influence on the user's health.

Electromagnetic radiation (EMR) with a variety of intensities within the aforementioned frequency range can aggravate changes in the state of the cardiovascular, central nervous and endocrine systems thereby eliciting a diverse variety of diseases and also exert influences on the physical and chemical processes in biosystems. This produces stresses at the submolecular and molecular levels in cells, organs and tissues which puts them in a state of functional stress and enables their subsequent functional and structural change (3).

In a series of studies (4 - 6) it was established that microwave radiation induces greater thermal damage in the cells of bacteria, mono-cellular organisms and animals than the equivalent heating load. It can be presumed that one of the reasons for that is a distinctive mechanism of delivering energy to the heat-susceptible cellular targets by microwave radiation and convectional means.

In separate publications (5) devoted to the study of the effects on humans by the electromagnetic fields from cellular telephones acting in the area of the head of the user, it is established that the field contributes to the development of a moderately obvious bradycardia and increases the electrokinetic activity in certain nuclei or nodes (букльного эпилета - bukal'nogo epileta).

What is described above indicates the timeliness and importance of further studies to determine the effects of cellular radiotelephones on humans.

The aim of our research work was to study the influence of microwave radiation emitted by cellular radiotelephones on the functional condition of the central nervous and cardiovascular systems of the users of such communications systems.

In order to study the influence of cellular radiotelephones on the functional condition of the central nervous and cardiovascular systems of the users of such communications systems, complex physiological studies were carried out with triple repetition of every measuring technique applied on 15 subjects aged 21 to 28. Each subject was exposed to the radiation once a day.

At the start of a run, background values of the physiological indicators were measured for each subject (with the source of exposure absent). Then the same physiological indicators were examined with a non-functioning radiotelephone which had been close to the subject's head for 3 minutes. Finally, a record of the given indicators was taken after the radiotelephone had been on for 3 minutes.

A "Benefon" (Finland), Model TDP-52-SN3, mobile cellular radiotelephone operating in the frequency range of 453-458 MHz, with an output power of 2.0 W and microwave radiation emission level of from 950 to 1250 $\mu W/cm^2$ was used as a source of exposure.

The central nervous system functional condition study was carried out by recording the latent period of the simple Visual-Motion Reaction (VMR) using a chronoreflexometer, by determining the Fusion Flicker Frequency (FFF) and by testing the individual's attention and intellectual serviceability using modified (alpha-numeric) Platonov's tables. The functional condition of the cardiovascular system was examined using a "Bioset-8000" (Germany) to capture electrocardiographic data with evaluation of the following indicators: the lengths of the R-R, Q-T and P-T intervals; the amplitude and duration of the T spike and the frequency of heart contractions.

The research that was carried out has shown that the background results for the functional condition of the central nervous and cardiovascular systems of radiotelephone users differ insignificantly from the results obtained when the radiotelephone was not operating (sham exposure).

Thus the parameters FFF and VMR have increased by only 0.2 Hz and 6.4 ms while in a correcting task the number of symbols checked decreased by 0.6, and the number of errors made increased by only 0.035 but the differences have not been statistically verified.

The effect of the microwave radiation on the user results in an increase in the light signal perception frequency and the latency time for the VMR. Statistically significant results ($P<0.02$) have been obtained indicating an increase in FFF by 2.1 Hz compared to that for the turned off radiotelephone and by 2.3 Hz compared to the background value.

The latency time for the VMR is significantly ($P<0.05$) increased by 20.3 ms compared to the turned off radiotelephone and by 26.7 ms compared to background value.

A reduction in central nervous system activity for users was more obvious following the operation of the radiotelephone. The number of symbols checked diminished by 2.2 while the number of mistakes made increased by 2.9 times compared to background and by 2.1 times compared to the turned off radiotelephone but the results were not statistically significant.

The dynamic observations from the examination of the cardiovascular system of a user have indicated that the differences in the observed indicators (for the turned-off radiotelephone and the background data) are minor and not statistically significant. However, it should be noted that the frequency of the heart rhythm, amplitude and duration of the T-wave had a tendency to decrease while the duration of the R-R, Q-T and P-T intervals increased insignificantly.

Cellular radiotelephone usage leads to significant decrease in T-wave amplitude by 0.417 mm ($P<0,05$) compared to the value with the radiotelephone turned off, and by 0.6 mm ($P< 0,02$) compared to the background value.

The T-wave duration decreased significantly by 0.030 s ($P<0,02$) compared to that obtained with the radiotelephone being off and by 0.041 s compared to the background value.

The heart rhythm frequency for a user after operation of the radiotelephone showed a tendency toward bradycardia and decreased by 4.46 beat per min compared to that with the radiotelephone turned off and by 6.05 beat per min compared to the background value although the differences were not statistically significant.

The electromagnetic radiation emitted by the cellular radiotelephone causes a decrease in the R-R and Q-T intervals, both in the turned-off condition and in the background. These differences, however, are neither so substantial nor significant, apparently owing to the short duration of the user's exposure to the EMF, but could indicate the character and direction for changes in these parameters.

The results obtained are also substantiated by data from other scientists (7-9) which have suggested that the appearance of bradycardia under the influence of low-level microwave radiation is caused by disturbances in central and peripheral innervations associated with mechanisms regulating heart activity.

Therefore, the results obtained permit us to draw the following conclusions:

- mobile cellular radiotelephones with output powers of 1-5 W are sources of high intensity microwave radiation which exceeds the level permissible for users by 2.5 to 16.5 times and produce adverse effects on the user

- the effect of microwave radiation from radiotelephones on the users' health leads to known changes in the physiological indicators of the central nervous and cardiovascular systems. FFF and VMR increase and T- wave amplitude and duration decrease.

- the magnitude and direction of the physiological shifts in cellular radiotelephone users gives evidence of a pronounced stress in their adaptive response mechanisms.

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